WELCOME TO THE COURSE

ON

MICRO MACHINING PROCESSES

BY

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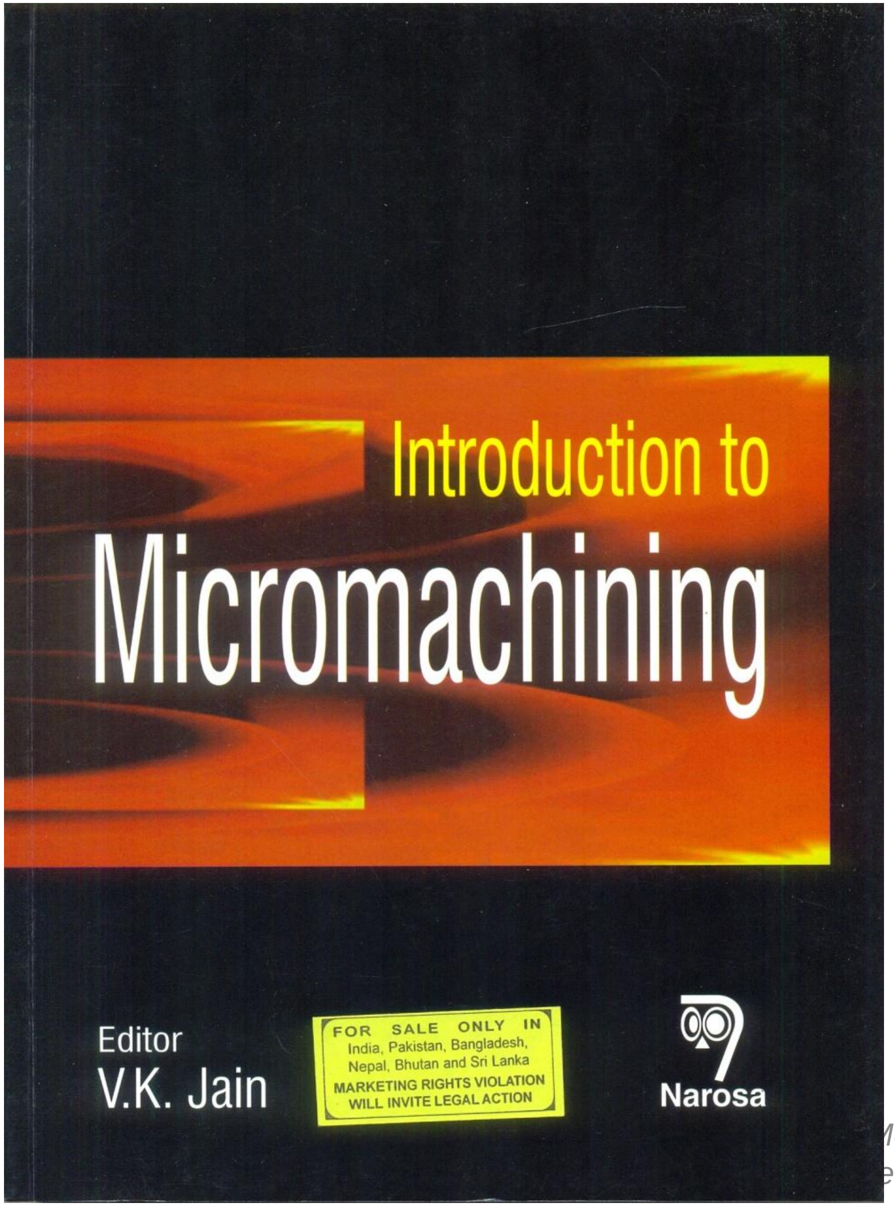
ORGANISATION

- TEXT BOOKS
- CHAPTERS TO BE COVERED IN THIS COURSE ON "MMPs"
- WHY DO YOU NEED MMPs
- CLASSIFICATION OF MMPs
- EVOLUTION AND WORKING PRINCIPLES OF SOME AMPs
- APPLICATIONS OF MMPs
- CONCLUSIONS

ADVANCED MACHINING PROCESSES



Introduction to

Micromachining

Editor

V.K. Jain

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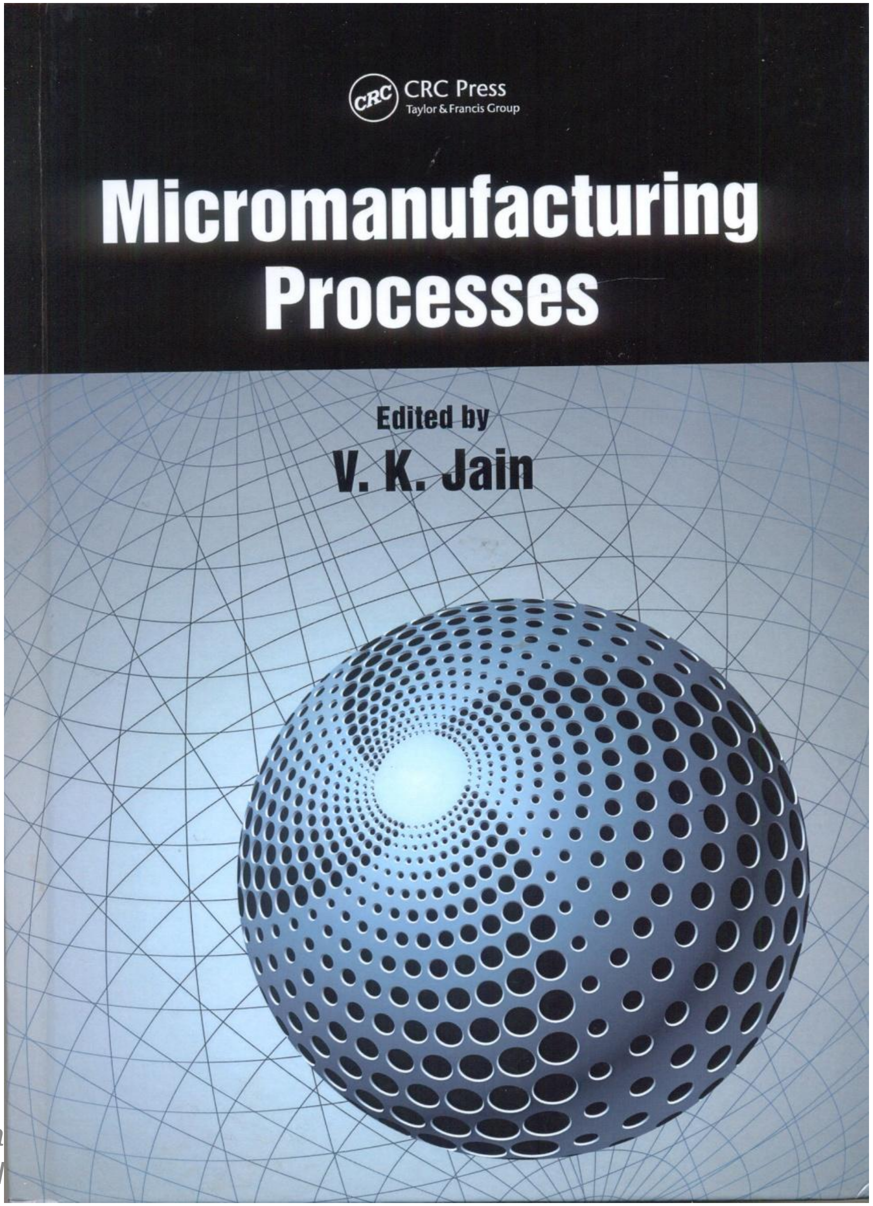
Narosa



CRC Press
Taylor & Francis Group

Micromanufacturing
Processes

Edited by

V. K. Jain

Grading Policy

Mid Sem. Exam--> 30 %
End Sem. Exam→ 40 %
Term Paper → 15%
Lab. Visits → 05%
Attendance →05%
Quizzes (unannounced)--→05%

For getting “D” or better grade, one should have minimum 30 % marks in both theory exams (Mid Sem. + End Sem.) and 35 % in total. For getting ‘E’ , One should have 25 % in theory and 30 % in total.

TEXT BOOKS

BOOKS

- ***INTRODUCTION TO MICROMACHINING*, V.K.JAIN (EDITOR) PUBLISHED BY NAROSA PUBLISHERS, N EW DELHI (2009). (second Edition)**
- **MICROMANUFACTURING PROCESSES BY V. K. JAIN (Editor), CRC PRESS.**
- ***ADVANCED MACHINING PROCESSES* BY V.K JAIN , ALLIED PUBLISHERS, NEW DELHI.**
- ***NON- CONVENTIONAL MATERIAL REMOVAL PROCESSES* BY V.K.JAIN, BLOCK-4, INDIRA GANDHI NATIONAL OPEN UNIVERSITY (IGNOU), NEW DELHI**

Reference Books

- MICROMACHINING METHODS BY J.A. Mc GEOUGH, CHAMPAN AND HALL, LONODON

TOPICSTO BE COVERED

SUBJECT AREAS

S.N	TOPIC
1	INTRODUCTION TO THE COURSE & CLASSIFICATION OF MMPs
PART – 1 : MECHANICAL TYPE ADVANCED MICRO MACHINING PROCESSES	
2	ABRASIVE JET MICRO MACHINING (AJMM)
3	ULTRASONIC MICRO MACHINING (USMM)
4	ABRASIVE WATER JET MICRO MACHINING (AWJMM)
PART – 2 : ABRASIVE BASED NANO FINISHING PROCESSES	
5	ABRASIVE FLOW FINISHING (AFF)
6	CHEMOMECHANICAL POLISHING (CMP)

SUBJECT AREAS

S.N	TOPIC
7	MAGNETIC ABRASIVE FINISHING (MAF)
8	MAGNETORHEOLOGICAL FINISHING (MRF)
9	MAGNETORHEOLOGICAL ABRASIVE FLOW FINISHING (MRAFF)
10	MAGNETIC FLOAT POLISHING (MFP)
PART – 3 : THERMOELECTRIC TYPE MICRO MACHINING PROCESSES	
11	ELECTRIC DISCHARGE MICROMACHINING (EDMM)
12	WIRE EDM , EDDG, ELID
13	LASER BEAM MICROMACHINING (LBMM)
14	ELECTRON BEAM MICROMACHINING (EBMM)

SUBJECT AREAS

S.N	TOPIC
PART – 4 : CHEMICAL AND ELECTROCHEMICHAL TYPE ADVANCED MACHINING PROCESSES	
15	ELECTROCHEMICAL MICROMACHININIG (ECMM)
16	ELECTROCHEMICHAL MICRO DEBURRING
17	CHEMICHAL AND PHOTOCHEMICAL MICROMACHINING
	PART-5 : TRADITIONAL MECHANICAL MICROMACHINING PROCESSS
18	MICRO TURNING
19	MICRO MILLING

SUBJECT AREAS

S.N	TOPIC
20	MICRO DRILLING
	PART- 6 : MISCELLANEOUS TOPICS
21	FOCUSSED ION BEAM (FIB) MACHINING
22	SELECTION OF MICRO MACHINING PROCESSES
23	CONCLUDING REMARKS

INTRODUCTION

- *In today’s high tech engineering industries, the designer’s requirement for the component are stringent, such as:*

➢ ***Extraordinary properties of materials*** *(say, high Strength, high heat resistant, high hardness, corrosion resistant etc.).*

➢ ***Complex 3D component*** *(say, turbine blade).*

➢ ***Miniature features*** *(filters for food processing and textile industries having a few tens of micrometer as hole diameter and thousands in numbers).*

➢ ***Nano level surface finish on complex geometries which are impossible to achieve by any traditional methods*** *(say , thousands of turbulated cooling holes in a turbine blade, making & finishing of microfluidic channels in the electrically conducting and non-conducting materials (say, glass, quartz, ceramics)).*

- *Such features on a component can be achieved only through the* ***advanced manufacturing processes*** *in general and* ***advanced machining processes in particular.***

PRESENT DAY DEMAND TRENDS IN INDUSTRIES
(AEROSPACE , MISSILES , AUTOMOBILES, NUCLEAR REACTORS, ETC.)

ENGG. MATERIALS HAVING MUCH SUPERIOR PROPERTIES

- ULTRAHIGH STRENGTH , HARDNESS
- VERY HIGH TEMPTURE RESISTANCE
- DIFFICULT TO MACHINE BY CONVENVENTIONAL MACHINING METHODS

WORK PIECE MATERIAL HARDNESS >> TOOL MATERIAL HARDNESS

HOW TO SOLVE THE PROBLEM ?

⬇

ADVANCED MICRO MACHINING PROCESSES

WORKPIECE HARDNESS DOES NOT MATTER IN AMMPs

METHODS OF MICRO FABRICATION

- **Material deposition**
  - Electro discharge Deposition (EDD)
  - Chemical vapor deposition (CVD)
  - Physical vapor deposition (PVD)
  - Rapid prototyping/rapid tooling (RP/RT)
  - LIGA
  - Electro chemical spark deposition (ECSD)
- **Material removal**
  - Traditional material removal processes
  - Advanced material removal processes
- **Metal forming (etc)**

Micro joining
Micro casting
Etc.

WHY DO YOU NEED OF MMPs?

Why miniaturization?

- *Minimizing energy and materials use in manufacturing*
- *Reduction of power budget*
- *Faster devices*
- *Increased selectivity and sensitivity*
- *Improved accuracy and reliability*
- *Cost/ performance advantages*
- *Integration with electronics, simplifying systems*

Size Comparisons in Micromanufacturing

- *100 micrometers ~ paper thickness, human hair*
- *8 micrometers ~ red blood cell, capillaries*
- *0.5 micrometers ~ visible light, machining tolerance*
- *0.07 micrometers ~ year 2010 IC production design rules*
- *0.0003 micrometers ~ atomic spacing in solids*

MICRO-PRODUCTS

NOWADAYS , FOCUS IS ON MINIATURIZATION THROUGH DEVELOPMENT OF NOVEL PRODUCTION CONCEPTS (SPECIALLY MICRO & NANO) FOR THE PROCESSING OF NON-CERAMIC MATERIALS.

MICROFABRICATION DEALS WITH ALL KIND OF MANUFACTURING PROCESSES BUT AT MICRO & NANO LEVEL.

THE REPLICATION OF MICROPARTS THROUGH MOLDING IS ONE OF THE PREFERRED ROUTES FOR MICROMANUFACTURE BECAUSE OF ITS MASS-PRODUCTION CAPABILITY AND RELATIVELY LOW COST.

HOWEVER IN THIS COURSE I WILL MAINLY CONCENTRATE ON MICRO ATTRITIOUS PROCESSES : "MICROMACHINING PROCESSES"

Material Removal Processes

- **Micro/nano machining**
  - *Traditional machining processes*
  - *Advanced machining processes*
- **Micro/nano finishing**
  - *Traditional finishing processes*
  - *Advanced finishing processes*

Micro / nano finishing

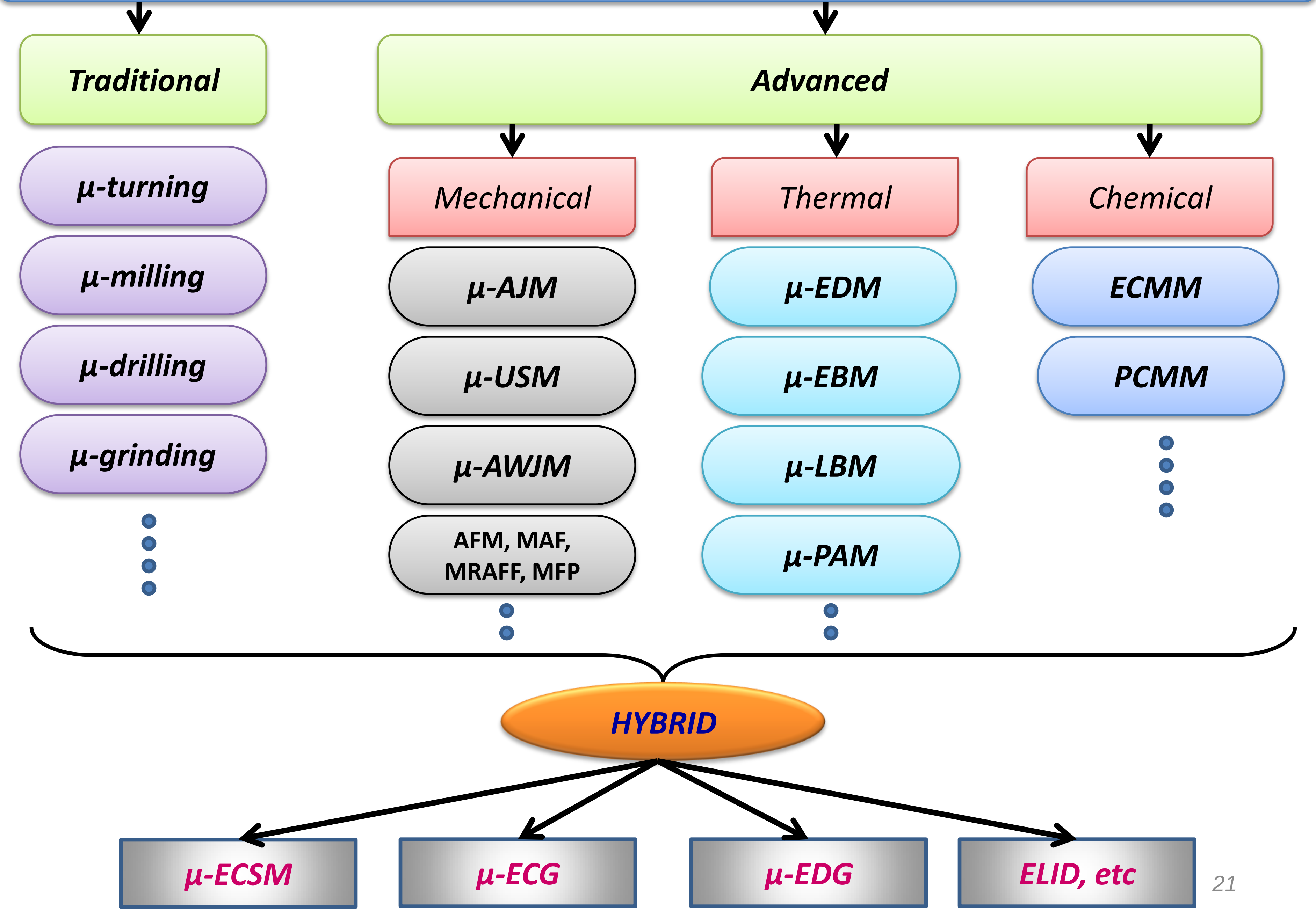
traditional

- *Grinding*
- *Lapping*
- *Honing*

Advanced

- *AFM*
- *MAF*
- *MRF*
- *CMP*
- *MRAFF*
- *ELID*
- *MFP*

- CLASSIFICATION Micromachining Methods BASED ON THE KIND OF ENERGY USED : MACHANICAL, THERMOELECTRIC, ELECTROCHEMICAL & CHEMICAL, BIOCHEMICAL



Traditional

- *μ-turning*
- *μ-milling*
- *μ-drilling*
- *μ-grinding*

Advanced

Mechanical

- *μ-AJM*
- *μ-USM*
- *μ-AWJM*
- AFM, MAF, MRAFF, MFP

Thermal

- *μ-EDM*
- *μ-EBM*
- *μ-LBM*
- *μ-PAM*

Chemical

- *ECMM*
- *PCMM*

HYBRID

- *μ-ECSM*
- *μ-ECG*
- *μ-EDG*
- *ELID, etc*

BASED ON THE PROPERTIES OF WORK MATERIAL TO BE MACHINED

- APPLICABLE ONLY FOR ELECTRICALLY CONDUCTING MATERIALS : ECM, EDM, EBM.
- APPLICABLE FOR BOTH ELECTRICALLY CONDUCTING & NON - CONDECTING MATERIALS: USM , AJM, LBM, ETC.
- APPLICABLE FOR NON – MAGNETIC MATERIALS : MAF, MRF, ETC.
- THERMAL CONDUCTIVITY, REFLECTIVITY, ETC. ALSO PLAY AN IMPORTANT ROLE IN SOME CASES: LBM

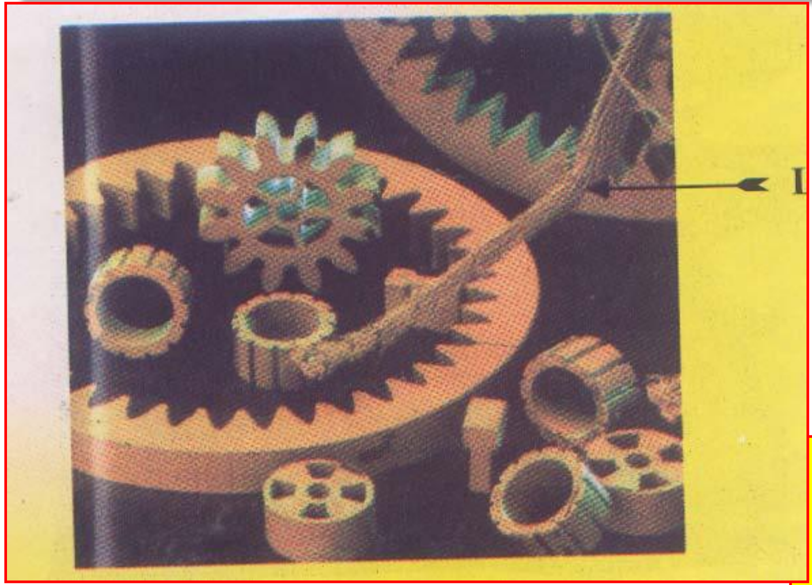
EXAMPLES: WHY WE NEED MICROMACHINING / MICROMANUFACTURING?

MICROMACHINING

MICRO + ***MACHINING***

Removal of material at micron level

- **Macro components but material removal is at micro / nano level**
- **Micro / nano components and material removal is at micro / nano level (Ex. MEMS, NEMS)**



Size: 2mm×2mm

Unfortunately , the present day notion is

↓

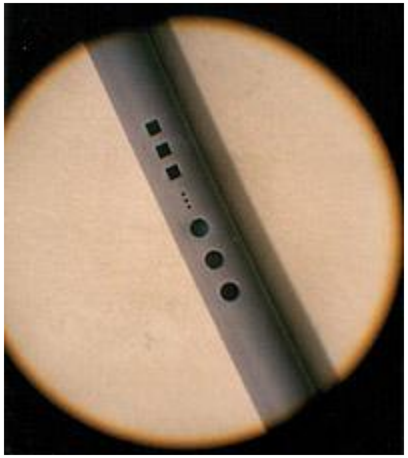
Machining of highly miniature components with miniature features. Literally it is NOT correct

MORE CORRECT DEFINITION IS material removal is micro/nano level
WITH NO CONSTRAINT ON THE SIZE OF THE COMPONENT

SOME MICROMACHINED PARTS

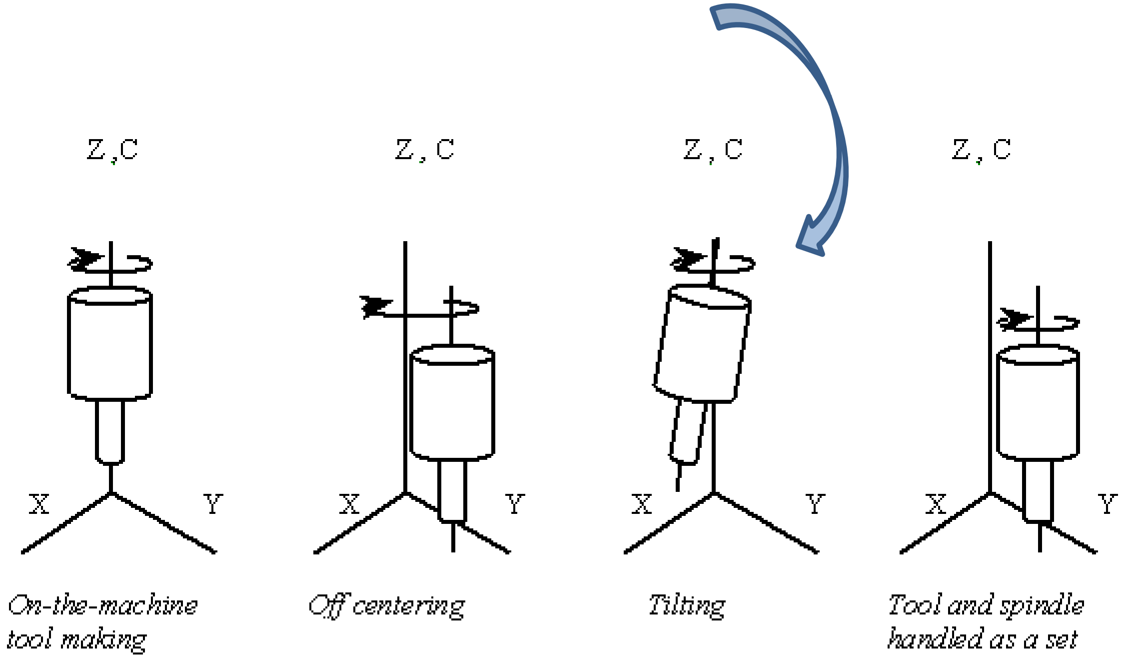
LASER-CUT STENTLIKE PATTERN IN MINIATURE STAINLESS- STEEL TUBE WITH 1.25-mm OD.

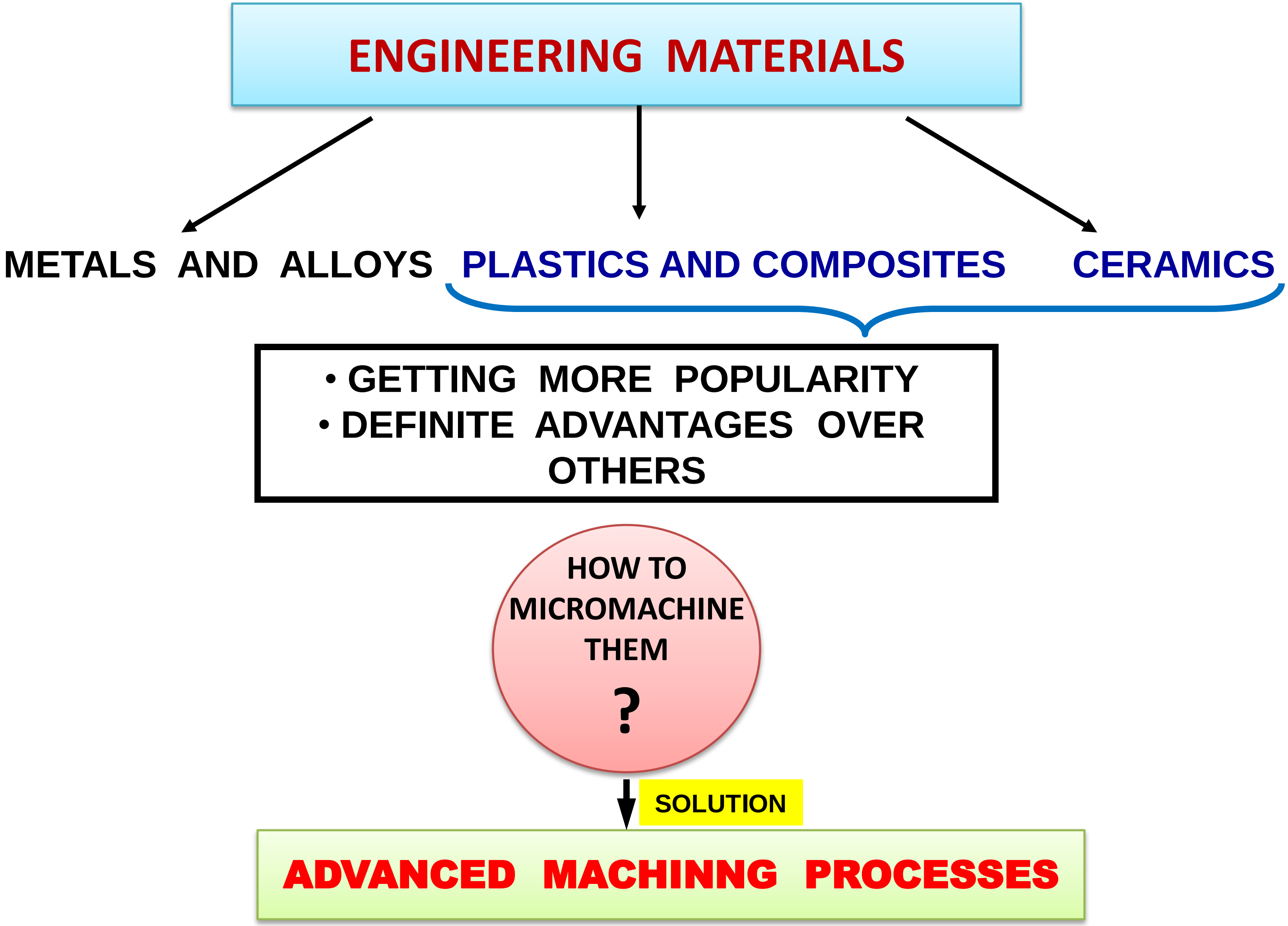
LASER-DRILLED HOLE(DIA. 15 µm) PATTERN IN POLYURETHANE TUBE



PROBLEMS IN MICROMACHINING

- MECHANICAL DEFORMATION
- THERMAL DEFORMATION
- SURFACE INTEGRITY
- GAP BETWEEN TOOL AND WORK PIECE
- COORDINATE SHIFT IN TOOL HANDLING





ENGINEERING MATERIALS

METALS AND ALLOYS

PLASTICS AND COMPOSITES

CERAMICS

- **GETTING MORE POPULARITY**
- **DEFINITE ADVANTAGES OVER OTHERS**

HOW TO MICROMACHINE THEM ?

SOLUTION

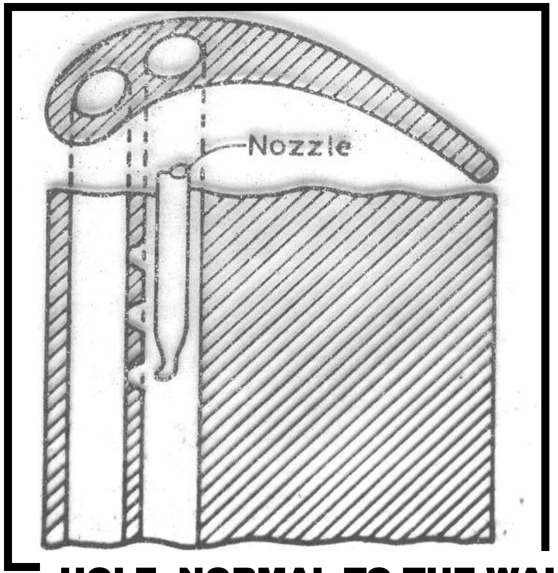
ADVANCED MACHINNG PROCESSES

WHY DO YOU NEED ADVANCED MICRO MACHINING PROCESSES ?

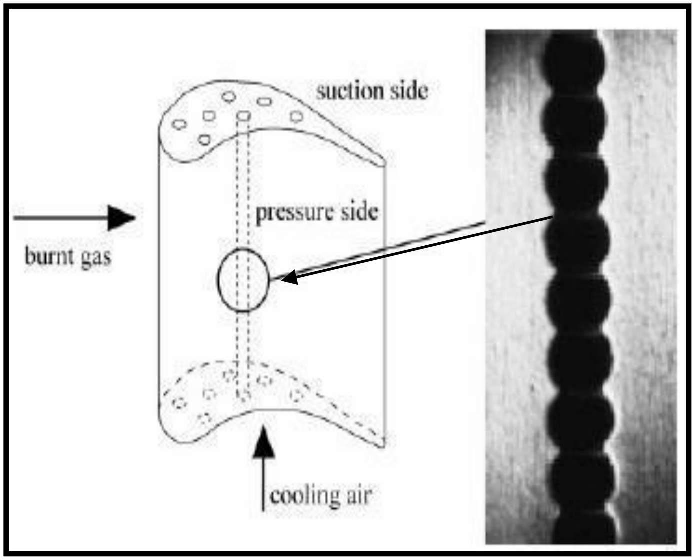
some examples

MICRO MACHINING OF COMPLEX SHAPED WORKPIECES?

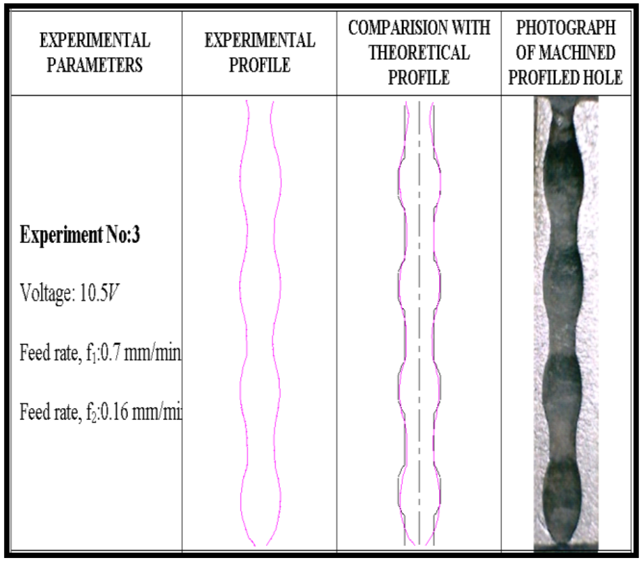
ELECTROCHEMICAL MACHINING



HOLE NORMAL TO THE WALL



Turbine Blade with cooling Holes

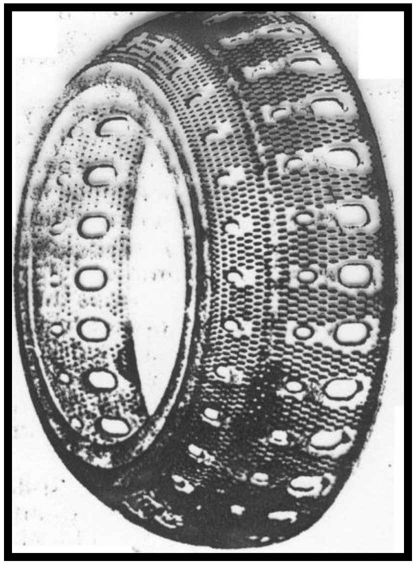


EXPERIMENTAL PARAMETERS	EXPERIMENTAL PROFILE	COMPARISION WITH THEORETICAL PROFILE	PHOTOGRAPH OF MACHINED PROFILED HOLE
Experiment No:3 Voltage: 10.5V Feed rate, f_1:0.7 mm/min Feed rate, f_2:0.16 mm/mi			

Contoured Hole Drilled In Inconel Using ECM

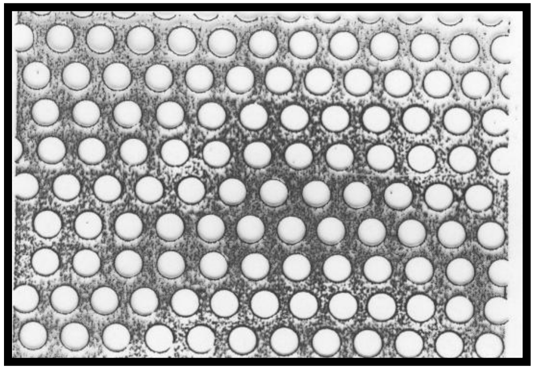
PATTERN OF HOLES DRILLED BY EBM

PART OF A HELICOPTER TURBINE " HOLES DRILLED BY EBM"



HOLE=0.09 mmϕ HOLES DENSITY = 4000/cm^2
WORKPIECE- S.S.;

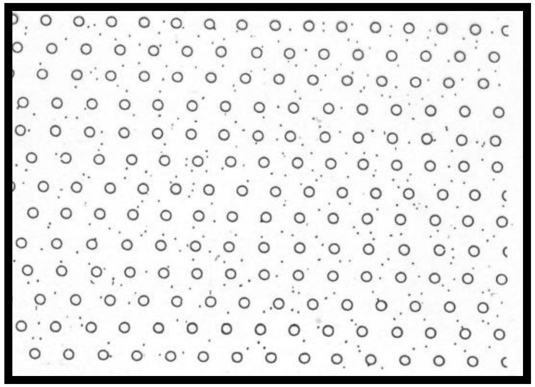
THICK = 0.2 MM; TIME = 10 μS/HOLE



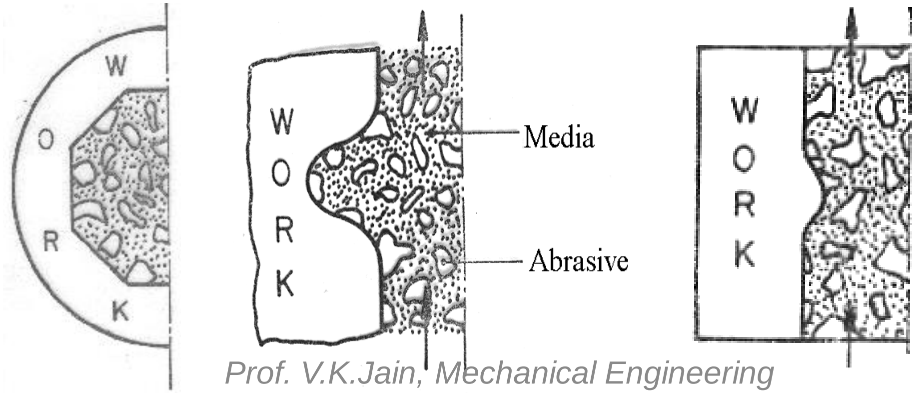
HOLE ϕ =0.006 mm (6 μm);

HOLES DENSITY = 200,000 / cm^2 ;

THICKNESS = 0.12 mm; TIME= 2μs / HOLE



AFF MEDIA ACTS AS A SELF-DEFORMABLE STONE

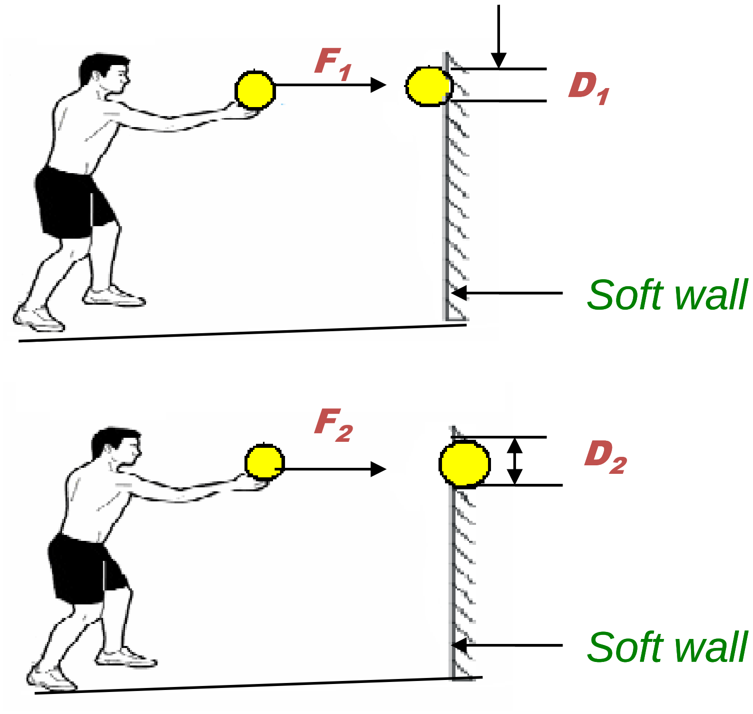


WORKING PRINCIPLE OF SOME MMPs

MECHANICAL ADVANCED MICROMACHINING PROCESSES

- *Abrasive jet micromachining (AJMM)*
- Abrasive water jet micromachining (AWJMM)
- Water *jet micromachining (WJMM)*
- *Ultrasonic micromachining (USMM)*

How Abrasive JET Machining (AJM) Works?

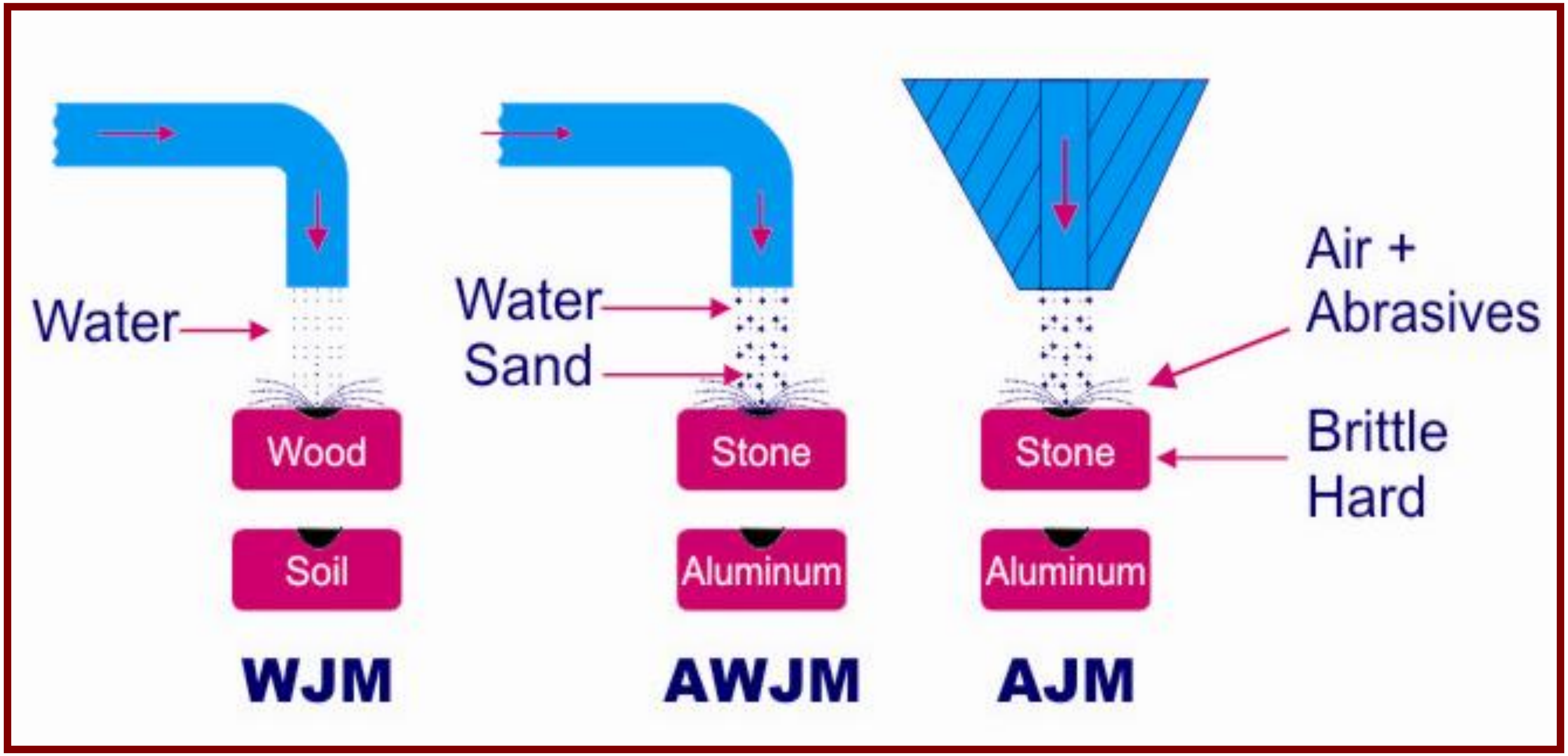


$F_2 > F_1$

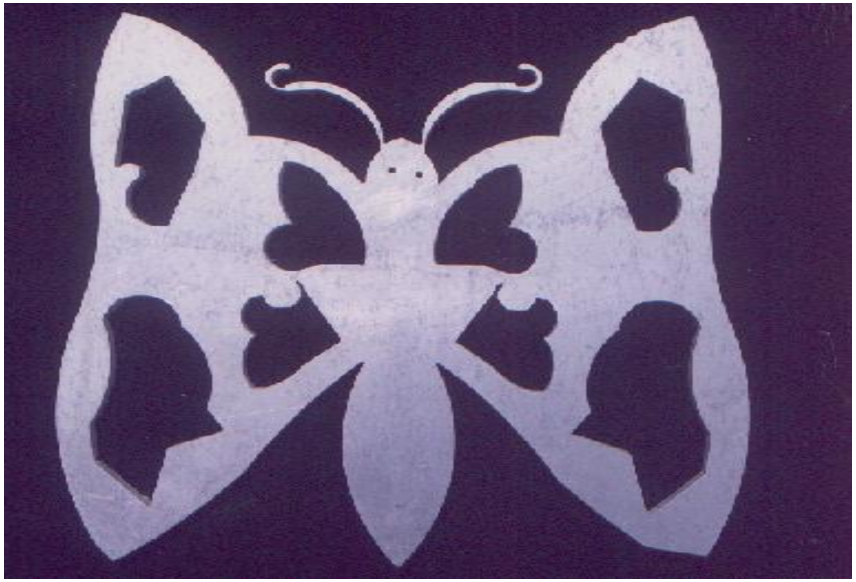
$D_2 > D_1$

- ***An young boy hits a ball twice on the wall with F1 & F2.***
- ***The ball makes a crater of size D_1 & D_2 such that $D_2 > D_1$ when $F_2 > F_1$.***
- ***D_2 & D_1 size = ø (Kinetic energy of the ball when hitting the wall).***
  = Force (or velocity of the ball with which it hits the wall,
  and mass of the ball)
- ***Abrasive Jet Machining (AJM) works on the same principle.***

WATER JET MACHINING (WJM), ABRASIVE WATER JET MACHINING (AWJM) , AIR JET MACHINING (AJM)



APPLICATIONS OF ABRASIVE WATER JET CUTTING (AWJC)



Granite cutting

COURTESY : IITM CHENNAI

PRINCIPLE OF MECHANICAL ADVANCED MICROMACHINING

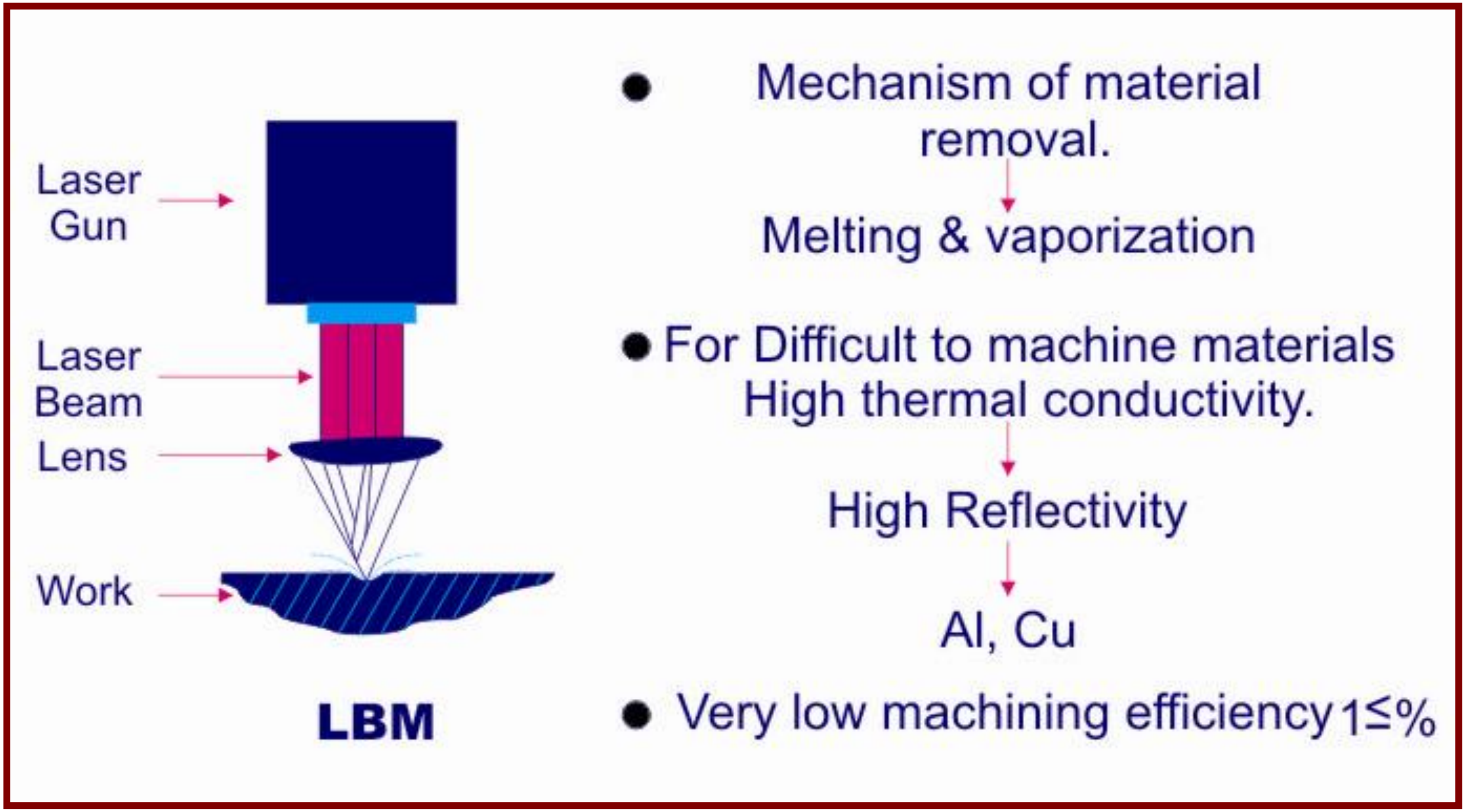
- ***Fine abrasive particles with high kinetic energy (KE) hit the workpiece at an angle and remove the material in the form of micro/nano-chips.***

- ***If the KE of the abrasive particle is high enough, then it will remove the material by shear deformation in case of ductile workpiece material and by brittle fracture if work piece material is brittle.***

APPLICATIONS

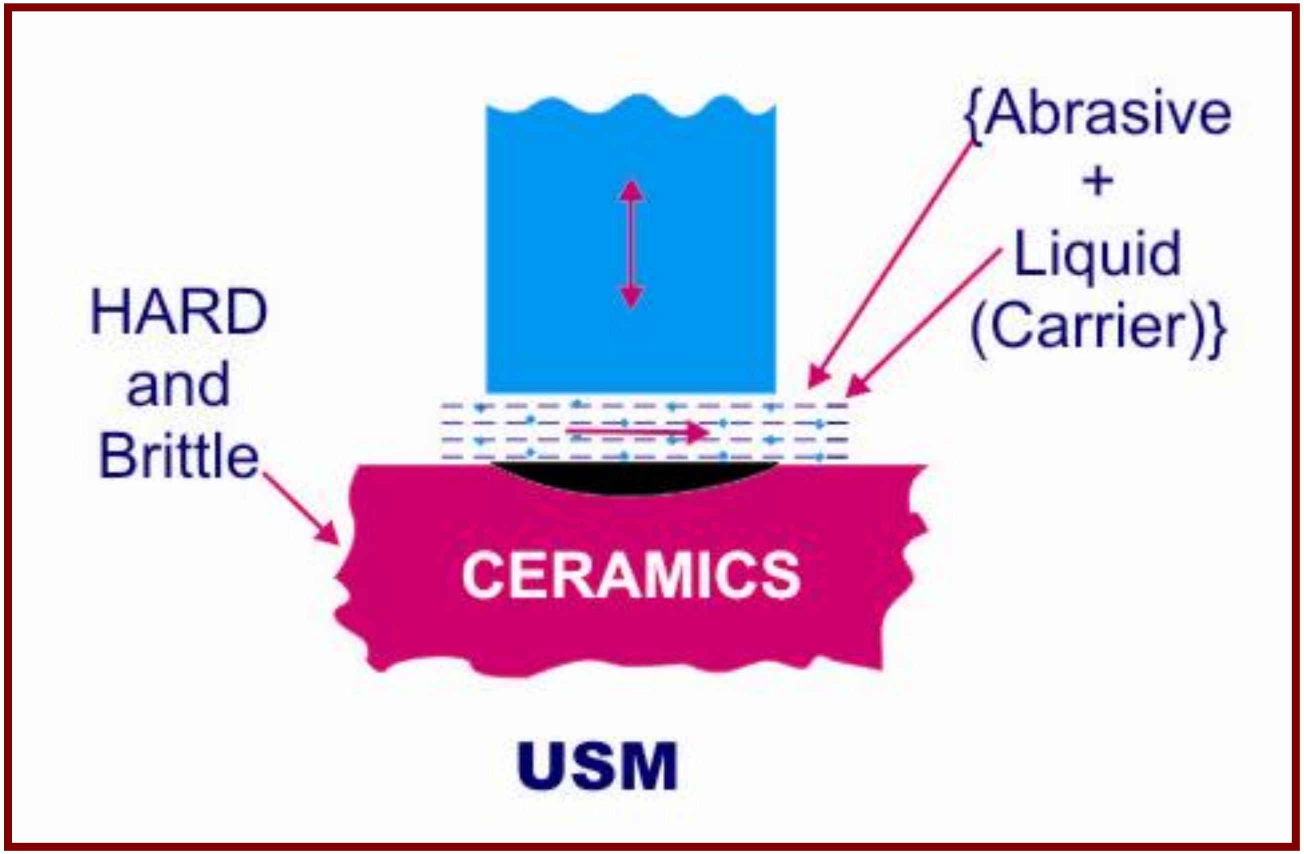
- Holes up to 66 μm deep can be drilled without employing special techniques.
- Micro burrs are clearly visible.
- This process is also useful for producing micro cavity.

LASER BEAM MACHINING (LBM)

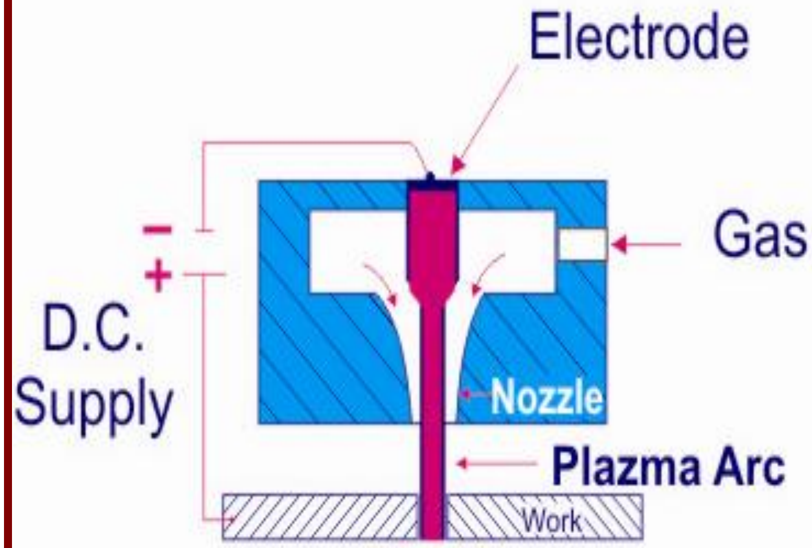


- Mechanism of material removal.
  ↓
  Melting & vaporization
- For Difficult to machine materials
  High thermal conductivity.
  ↓
  High Reflectivity
  ↓
  Al, Cu
- Very low machining efficiency 1≤%

ULTRASONIC MACHINING



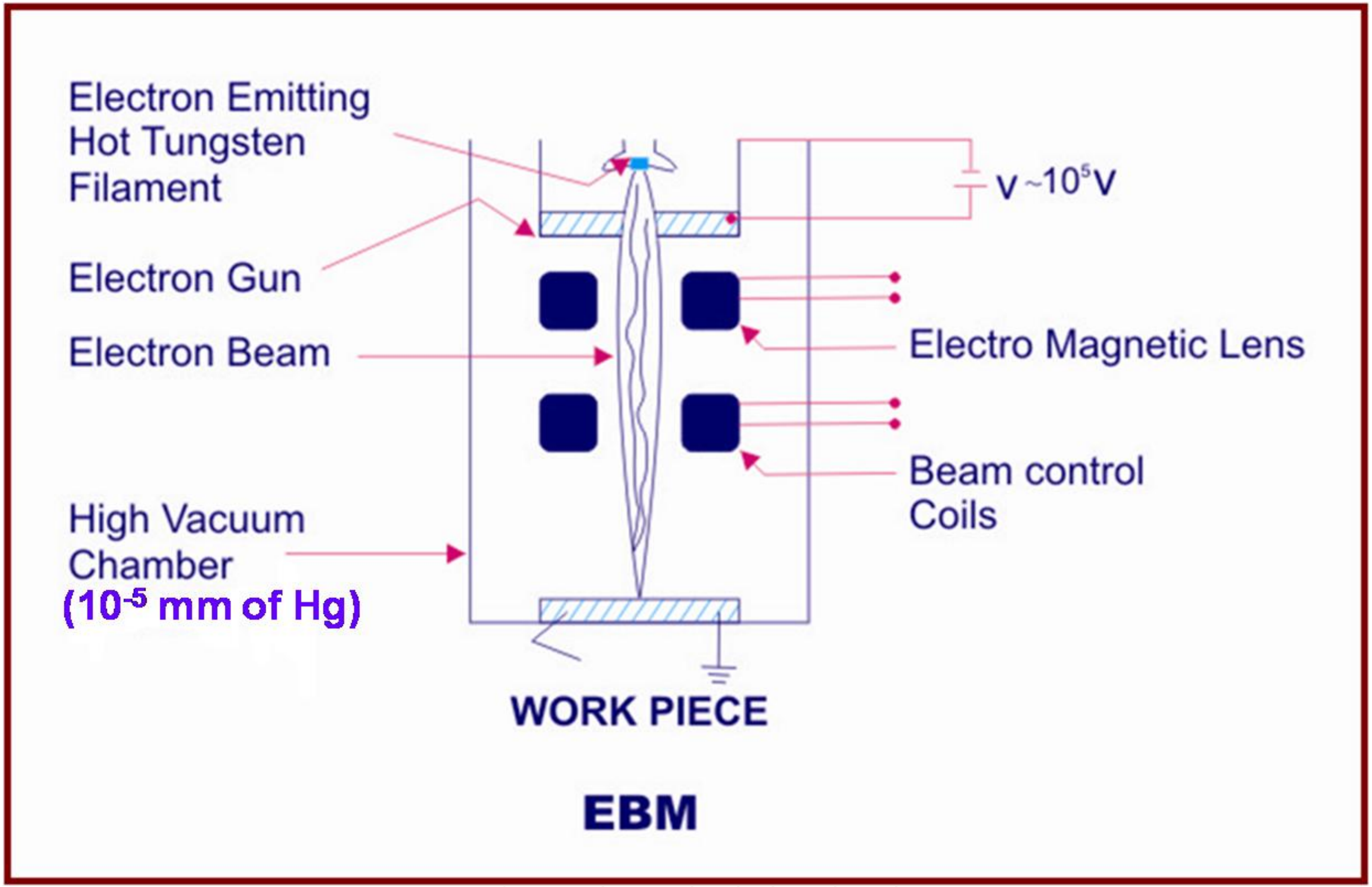
LASER BEAM MACHINING (LBM)



PAM

ALSO FOR SOFTENING OF WORK PIECE BY HEATING USING PLASMA ARC, THEN MACHINING

ELECTRON BEAM MICROMACHINING



FOCUSSED ION BEAM MACHNING

- SPUTTERING OFF: KNOCKING OUT ATOMS FROM THE WORK-PIECE SURFACE BY THE KINETIC MOMENTUM TRANSFER FROM INCIDENT ION TO THE TARGET ATOMS
- REMOVAL OF ATOMS WILL OCCUR WHEN THE ACTUAL ENERGY TRANSFERRED EXCEEDS THE USUAL BINDING ENERGY.

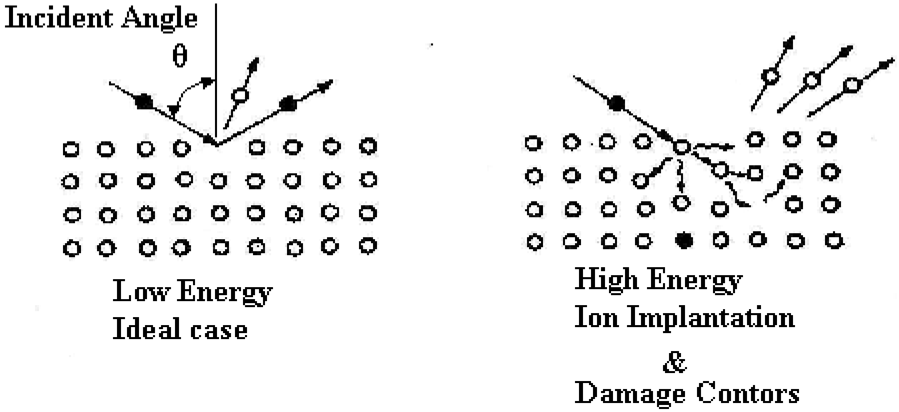
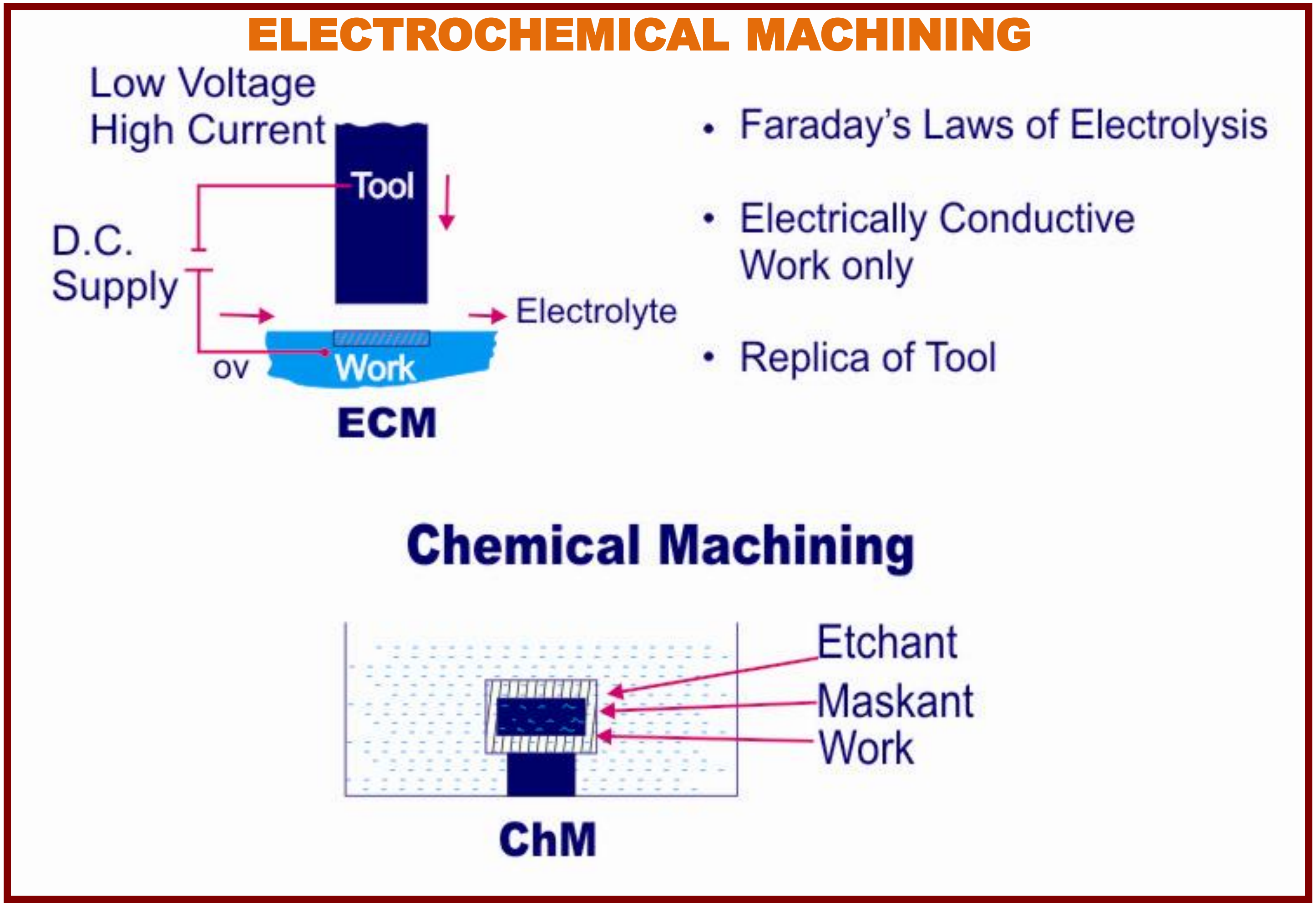


FIG. SCHEMATIC ILLUSTRATION

- AT SUFFICIENTLY HIGH ENERGY, THE CASCADING EVENTS WILL PENETRATE MORE DEEPLY INTO THE SOLID, SEVERAL ATOMS OR MOLECULES WILL BE EJECTED OUT AND THE BOMBARDING ION WILL BECOME IMPLANTED DEEP WITHIN THE MATERIAL.

ELECTROCHEMICAL & CHEMICAL MICRO MACHINING PROCESSES



ELECTROCHEMICAL MACHINING

- Faraday's Laws of Electrolysis
- Electrically Conductive Work only
- Replica of Tool

Chemical Machining

WORKING PRINCIPLE OF NANO FINISHING TECHNIQUES

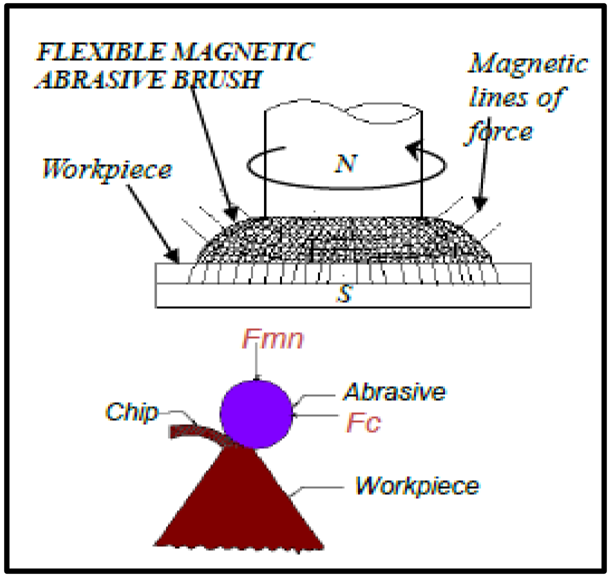
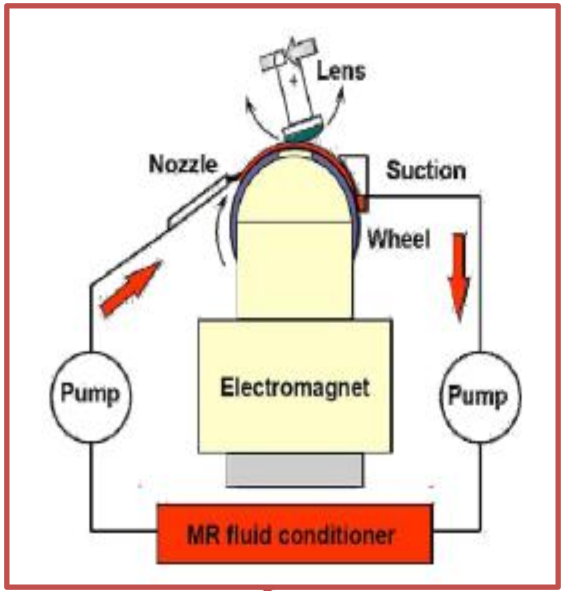
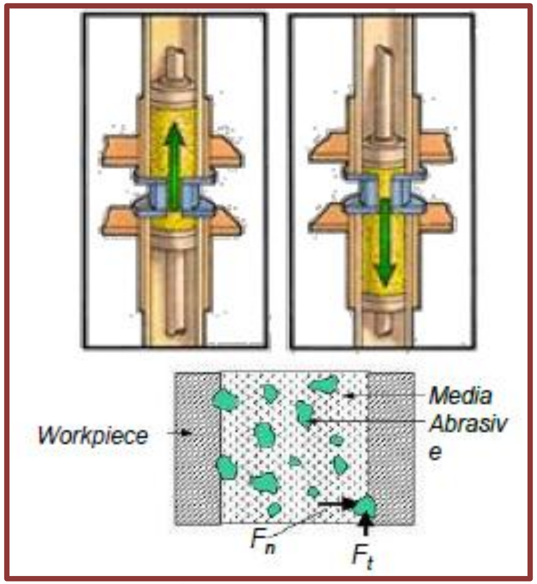


Fig: Magnetic Abrasive finishing (MAF)
Ref: MAF (Kremen,1994)



MRF

+



AFF

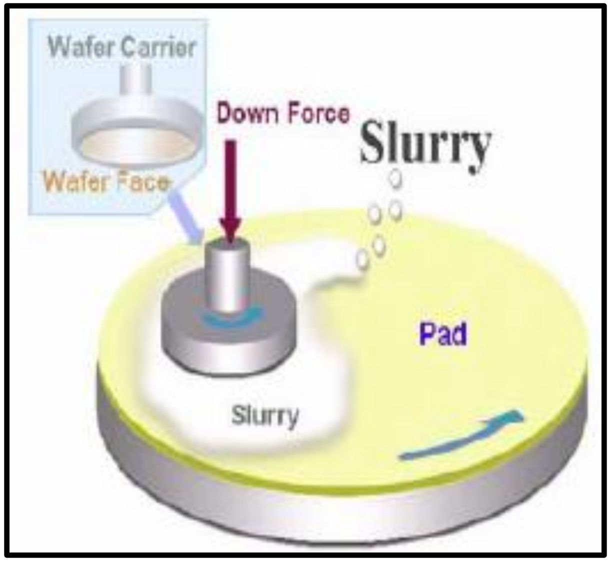
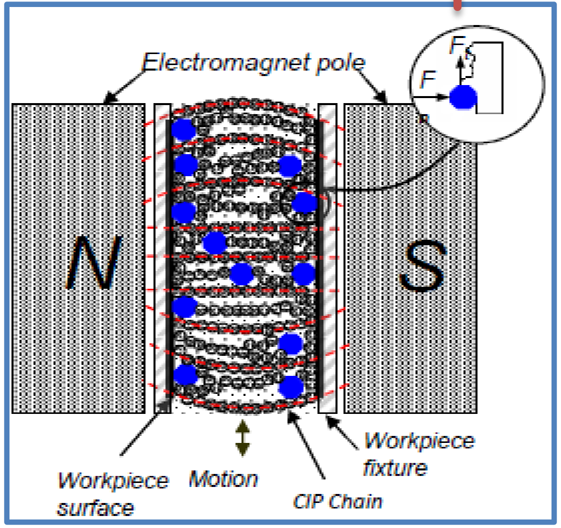


Fig: Chemo mechanical Polishing (CMP)
Ref: T.H. Tsai et al. (2003)



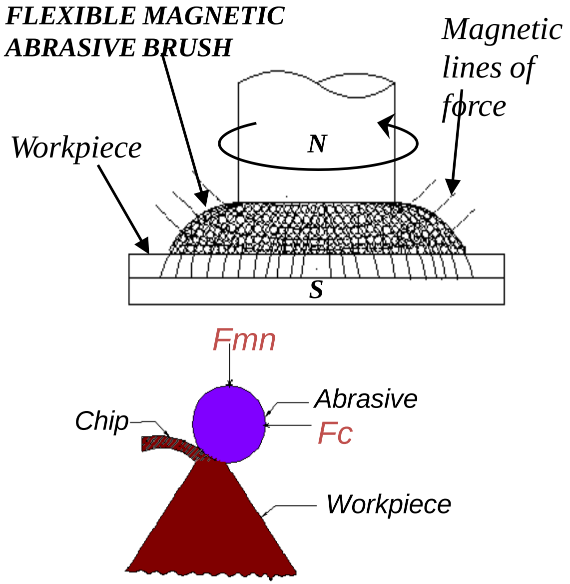
MRAFF

Ref: MRAFF (Jha and Jain, 2004)

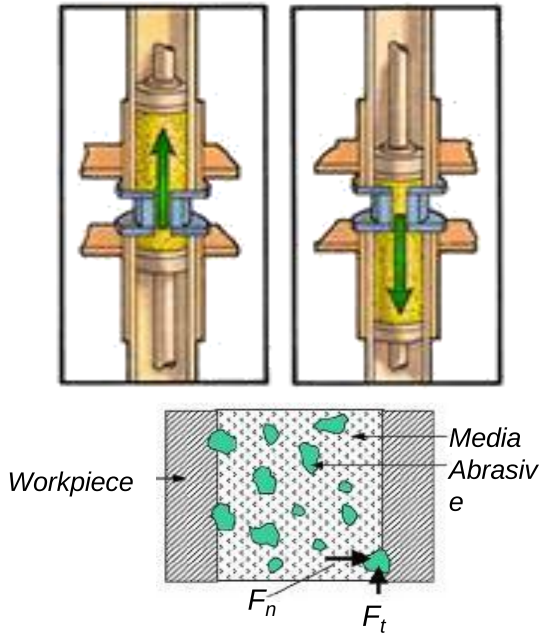
R-MRAFF PROCESS

MRF ✛ AFM ✛ ROTATION

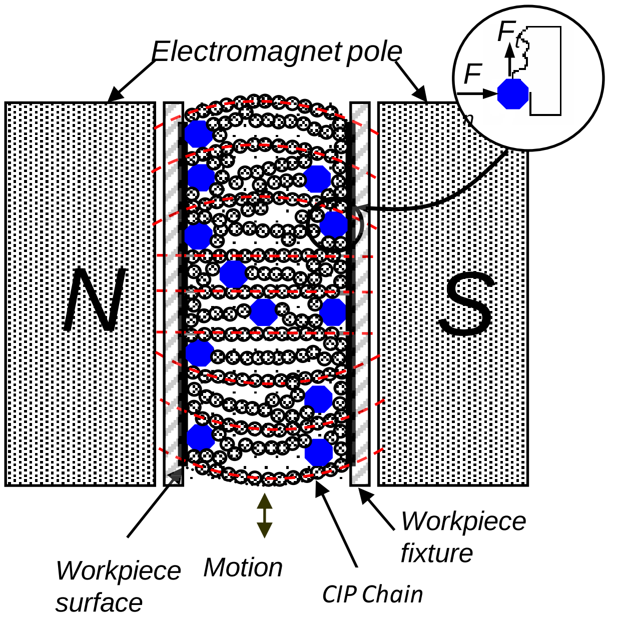
MAF



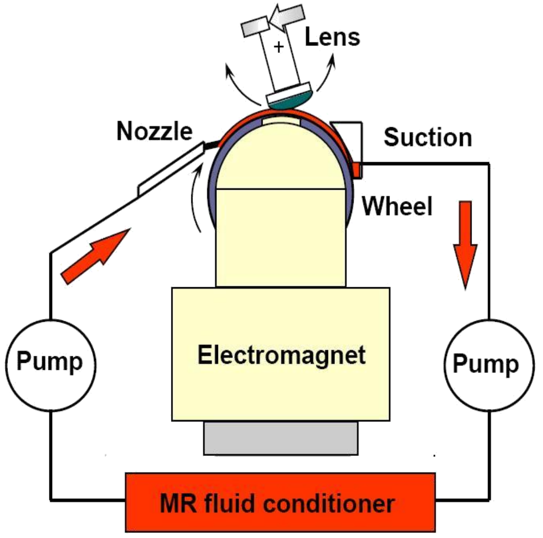
AFM



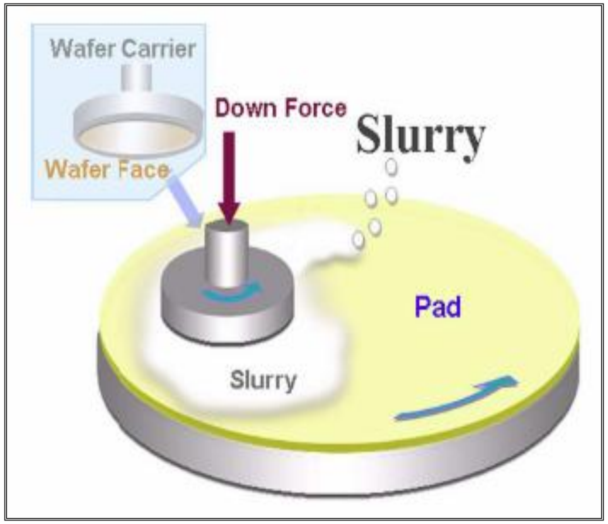
MRAFF



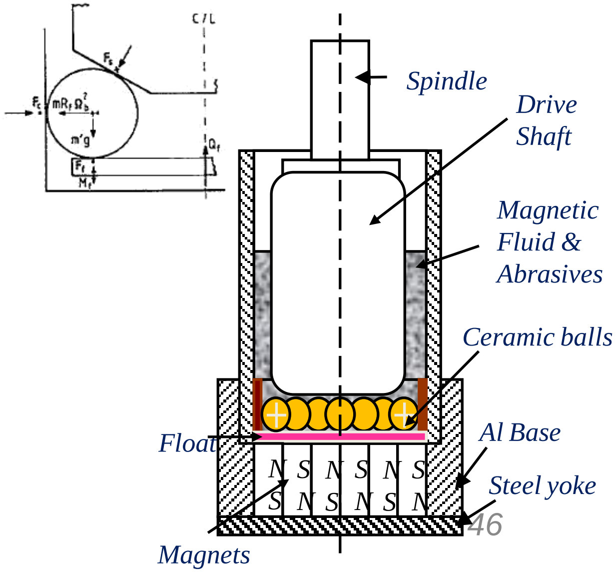
MRF



CMP



MFP



THEMAL ADVANCED MICROMACHINING PROCESSES

- **Electro discharge micromachining (EDMM)**
- ***Electro beam micromachining (EBMM)***
- **Laser beam micromachining (LBMM)**
- ***Plasma arc micromachining (PAMM)***

PRINCIPLE OF THERMAL ADVANCED MICROMACHINING PROCESSES

- Localized intense heat is produced which increases temperature of the workpiece in a narrow zone (i.e. Beam diameter), equal to its melting or vaporization temperature

- Which leads to removal of material at micro/ nano level in the form of debris (irregular shaped particles or spherical globules).

*Note: In case of IBM. An ion hits an atom at the top surface of the workpiece, and removes the material atom by atom or in the groups of atoms. There is no thermal damage to the workpiece in IBM

APPLICATION

- Some of the products include devices such as computer hard disc drive heads, inkjet printer heads, sensors, infrared images.
- *Micro electro-mechanical systems required fabrication with µm/ nm tolerance which is possible with these techniques.*
- Reduced hole *diameter, l*ower hole pitch and longer head can be manufactured by thermal micromachining processes.
- *Marking and engraving.*

ELECTROCHEMICAL & CHEMICAL ADVANCED MICROMACHINING PROCESSES

- **Electrochemical micromachining (ECMM)**
- ***Chemical micromachining (ChMM)***
- **Photo Chemical micromachining (PCMM)**
- **Electrochemical spark machining (ECSM)**
- **Electrochemical microdeburring (ECMDe)**

PRINCIPLE OF ELECTROCHEMICAL & CHEMICAL MICRO MACHINING PROCESSES

Electrochemical micromachining:

- *Electrochemical metal removal is an alternate wet etching process*
- *The workpiece made an anode and the tool as cathode in an electrolyte cell in which a nontoxic salt solution is used as an electrolyte*
- *Controlled metal removal takes place when the current (smooth D.C. Or Pulse D.C.) flow through the electrolytic cell*

Chemical micromachining:

- *It is an ancient process being used for engraving the metal for making ornaments and other products.*
- *It removes material in a controlled manner by the application of maskant and etchant.*
- *Maskant does not allow etchant to reach & react with work piece to dissolve it.*
- *Etchant dissolves workpiece material by chemical action.*

ADVANCED NANO FINISHING PROCESSES

- ***To finish surfaces to nano level, it is required to remove material in the form of atoms or molecules individually or in groups***

- ***Some processes such as Elastic Emission Machining (EEM) and Ion Beam Machining (IBM) work directly by removing atoms and molecules from the workpiece surfaces***

- ***While other processes based on finishing by abrasives, remove them (atoms and molecules) In clusters***

- ***Most of the nano finishing processes are using abrasive particles either suspended in liquid or held by the viscoelastic material, carbonyl iron particles, or by magnetorheological fluid As a carrier***

Micro/Nano Finishing

- **Traditional**
  - Grinding
  - Lapping
  - Honing
- **Advanced /Non-traditional**
  - AFM
  - MRF
  - MAF
  - MRAFF
  - CMP
  - MFP
  - ELID

CLASSIFICATION OF ADVANCED NANO-FINISHING PROCESSES

- ***Advanced abrasive finishing processes***

➢ *Abrasive Flow Machining (AFM)*

- ***Magnetic field assisted advanced finishing processes (AFPs)***

➢ *Magnetic Abrasive Finishing (MAF)*
➢ *Magnetic Float Polishing (MFP)*
➢ *Magnetorheological Finishing (MRF)*
➢ *Magnetorheological Abrasive Flow Finishing (MRAFF)*

- ***Magnetorheological fluids based processes***

➢ *Rotational Magnetorheological Abrasive Flow Finishing (R-MRAFF)*

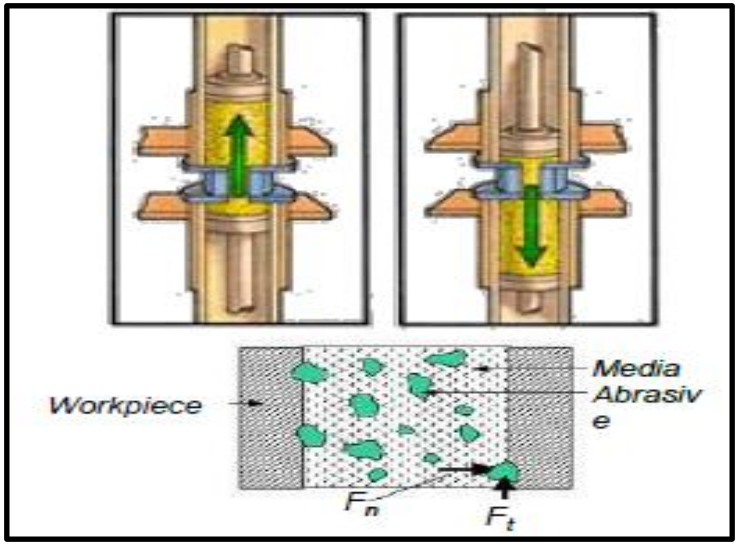


Fig: Abrasive Flow maching (AFM),
Ref: AFM (Jain and Jain, 1998)

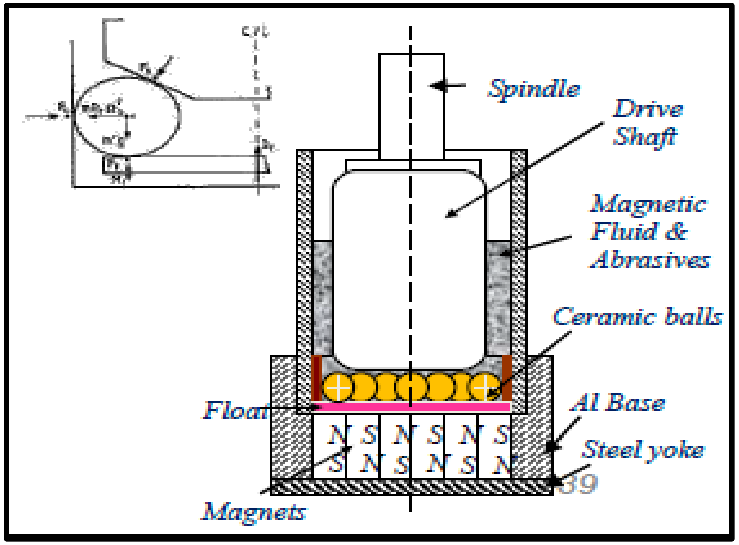
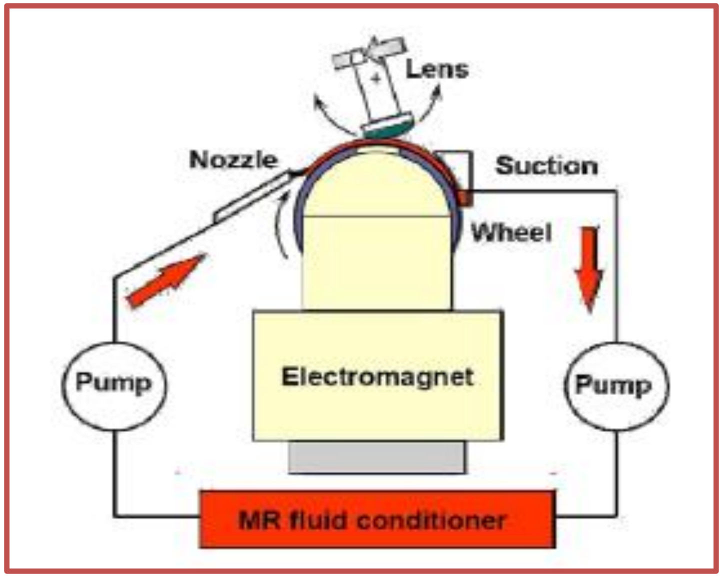
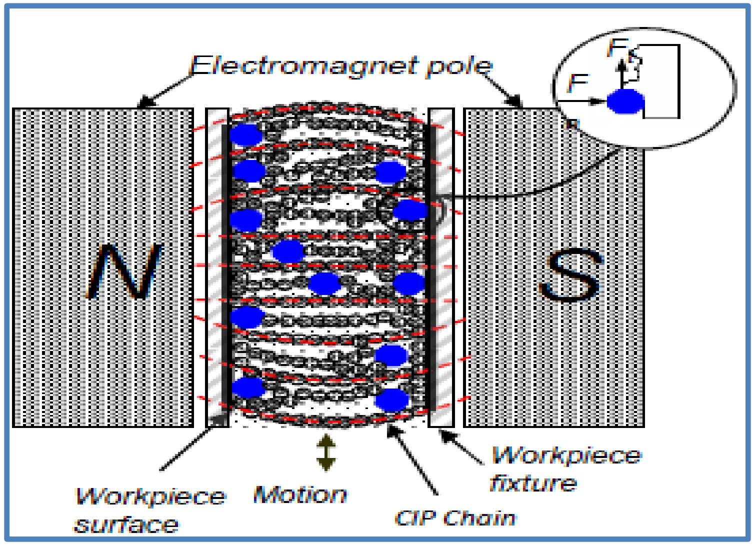


Fig: Magnetic Flot Polishing (MFP)
Ref: MFP (Komanduri et al., 1997)



Magnetorheological finishing (MRF),
Ref: MRF Kordonski and Jacobs1 et al., 1996 (QED technologies)



Magnetorheological Abrasive flow finishing (MRAFF)
Ref: MRAFF (Jha and Jain, 2004)

MAGNETO RHEOLOGICAL ABRASIVE FINISHING (MRF)

- *MRF was invented at the Luikov Institute of Heat & Mass Transfer in Minsk, Belarus in the late 1960s by a team led by William Kordonski and after some time they form a company known as **QED technology.***

- *MRF is a deterministic and magnetic field assisted precision finishing Process.*

- *MRF uses **MRP fluid** which is **invented by Rabinow** in late 1940s consist of*

➢ ***CIP** (Magnetic),*
➢ ***Abrasive Particle** (Non-magnetic)*
➢ ***carrier liquid** (Oil or water)*
➢ ***additives** (glycerol, grease)*

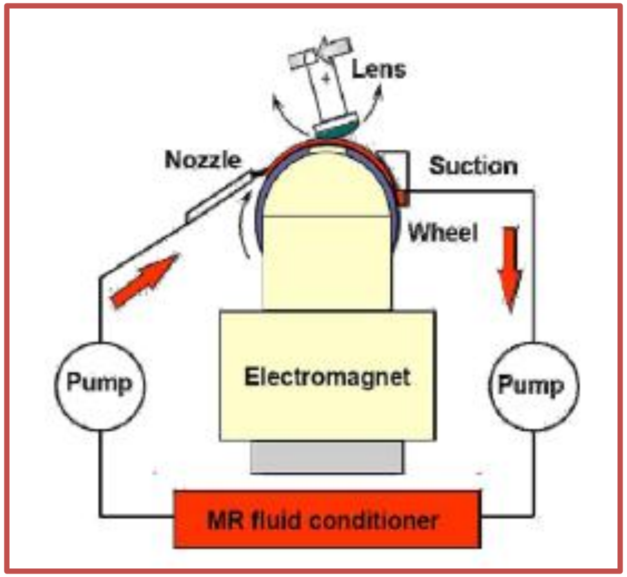


Fig : (a) Vertical wheel MRF machine
Ref: Kordonski and Jacobs1 et al., 1996 (QED technologies)

- ***MRP fluid** works as **polishing tool**.*

Application:

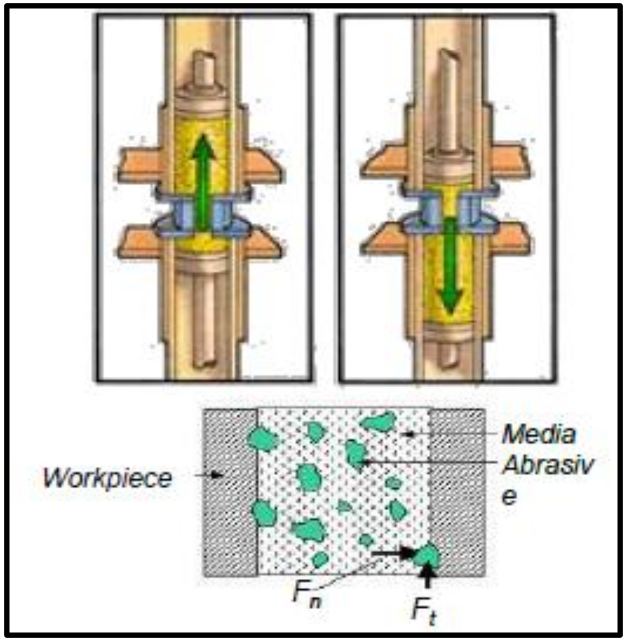
•MRF has been used for finishing a large variety of brittle material ranging from optical glasses to hard crystals.

Limitations:

➢ *Internal and specially complex surfaces can't be finished.*

ABRASIVE FLOW MACHINING (AFM)

- *AFM was developed **by Extude Home Corporation USA** in1960 as a method **to deburr ,polish** and **radius** difficult to reach surface like intricate geometries and edges by flowing a abrasive laden viscoelastic medium over them*



Abraisive Flow maching (AFM), Ref: AFM (Jain and Jain, 1998)

Key Component
- *Machine*
- *Tooling*
- *Abrasive Medium*

Process Input Parameters
- *Extrusion Pressure*
- *No. Of Cycle*
- *Grit Composition & Type*
- *Tolling & Fixture*

Application:

- ➢ *In industries such as Aerospace, medical , electronics, Automotive, Precision dies and mould as part Of manufacturing activities.*

Limitations:

- ➢ ***AFF is not deterministic process.***

CHEMO MECHANICAL POLISHING (CMP)

Chemical + *Mechanical* → *Chemo mechanical*

- *Basically CMP is used to polish the silicon wafer.*
- *Wafer-Pad-Slurry interactions*

Why CMP:

- *Local planarization*
- *Global planarization*

Principle:

- *CMP uses both chemical and mechanical type or material removal mechanism.*
- *Chemical reaction to soften material and than mechanically polish off this layer.*
- *Mechanical removal takes place due to abrading.*

Limitations:

- *This process is used for only flat surfaces.*
- *CMP is not deterministic in nature.*
- *Endpoint of CMP is a difficult to control for a desired thickness.*

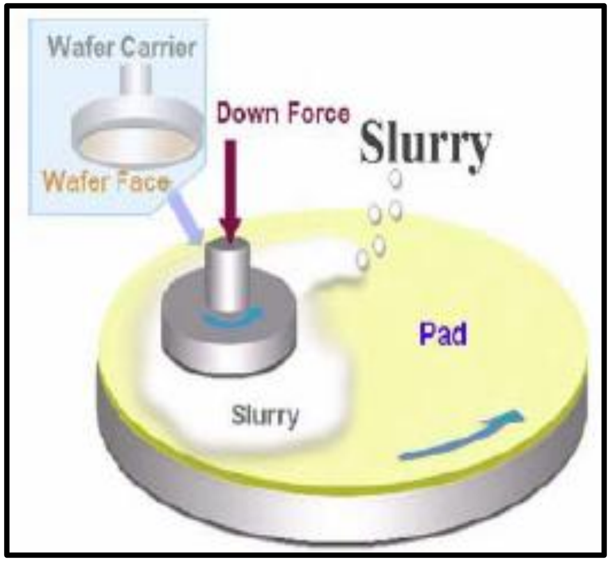


Fig: Chemo mechanical Polishing (CMP)
Ref: T.H. Tsai et al. (2003)

MAGNETIC ABRASIVE FINISHING (MAF)

- *In MAF finishing is performed by the application of magnetic field across the gap b/w the workpiece surface & the rotating electromagnet pole.*

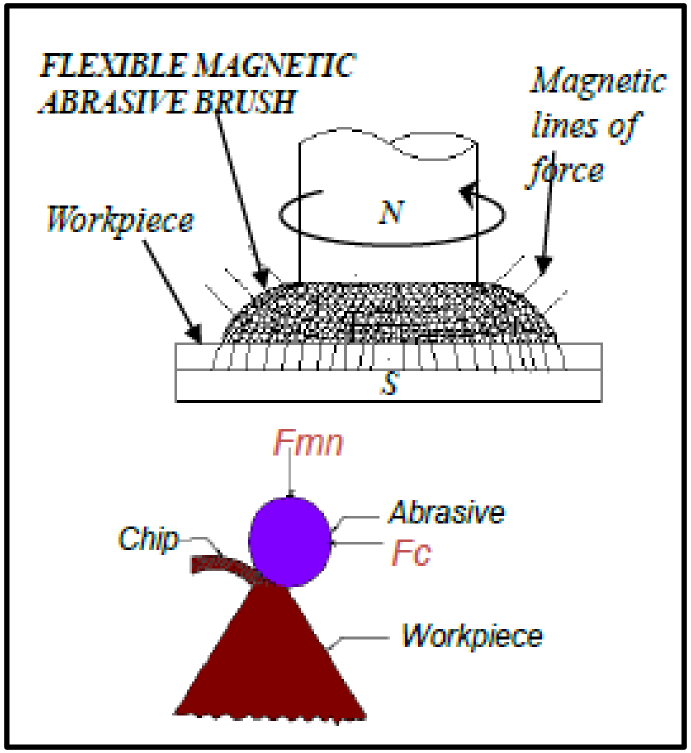
- *The magnetic abrasive particles are attracted with each other magnetically b/w magnetic poles along the lines of magnetic force forming a flexible magnetic abrasive brush.*

- *MAF was developed to produce efficiently and economically good quality finish on the internal and external surface of tubes as well as flat surface made of magnetic or non-magnetic material.*

➢ *8-9 nm surface roughness value (High surface finish)*

Limitations:

➢ *MAF can not be used for complex geometries.*



Magnetic Abrasive finishing (MAF)
Ref: MAF (Kremen,1994)

MAGNETIC FLOAT POLISHING (MFP)

- *Magnetic Float Polishing is a technique based on the Magnetohydrodynmic behaviour of the magnetic fluid which in the presence of magnetic field can levitate a non-magnetic float and abrasive particles suspended in it.*

- *The forces applied by abrasives are extremely small and controllable.*

- *When the magnetic field is applied the ferromagnetic particle in the ferrofluid are attracted downward to the area of higher magnetic field and upward buoyant force is exerted on all non-magnetic materials to push them to the area of lower magnetic field.*

- *The balls are polished by the abrasive particles mainly due to the action of the magnetic buoyancy force when the spindle rotates*

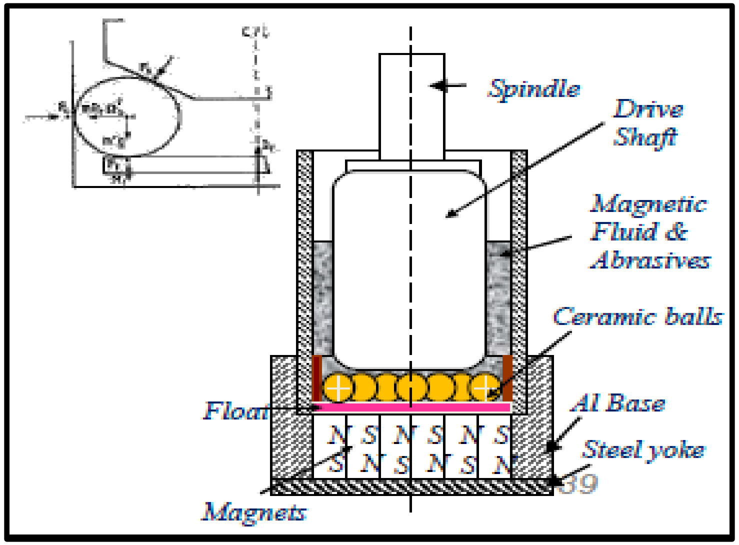


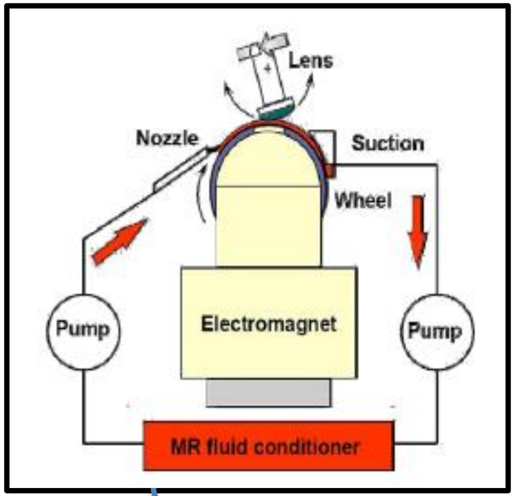
Fig: Magnetic Float Polishing (MFP)
Ref: MFP (Komanduri et al., 1997)

MAGNETORHEOLOGICAL ABRASIVE FLOW FINISHING (MRAFF)

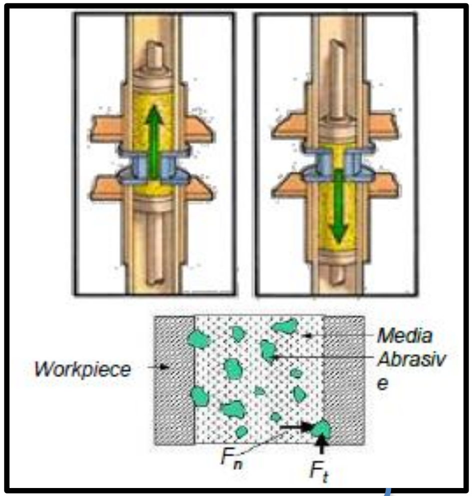
- *MRAFF is the hybrid finishing process to take the advantage of both the finishing process (MRF & AFF)*

- *It is deterministic process.*

- *Any complex geometries can be finished by this process.*



MRF



AFF

Limitations:

➢ *Non-uniform surfa*

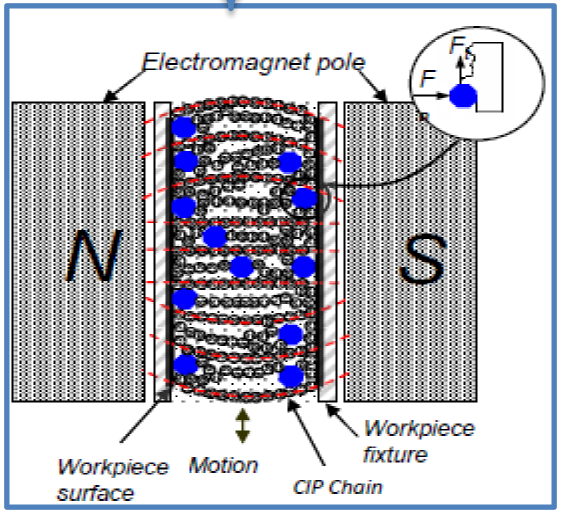
case of freeform sur

Why low finishing rate.....?

➢ *Low finishing rate.*

- *Interaction between the NMAPs and w/p surface is in straight line sweeping a small area.*

- *Only a small percentage of NMAPs which are on the periphery of the slug actually participate in the finishing operations.*



MRAFF

Ref: MRAFF (Jha and Jain, 2004)

ROTATIONAL - MAGNETORHEOLOGICAL ABRASIVE FLOW FINISHING (R-MRAFF)

How to increase the finishing rate in MRAFF

Solution

R-MRAFF PROCESS

MRF + **AFM** + **ROTATION**

- *One way to rotate the medium itself and other is to rotate the workpiece.*
- *Rotation of w/p is difficult in the existing MRAFF setup with the possible chance of leakage of medium.*
- *Therefore , rotation of the medium has been adopted by rotating the magnetic field and the process is named as (R-MRAFF).*

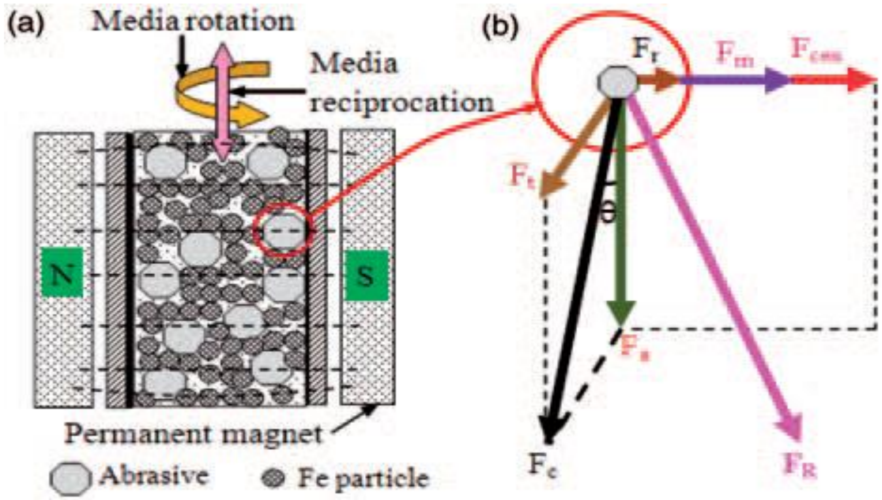


Fig: (a) Schematic of Fe particles chains structure and (b) force components acting on NMAP in R-MRAFF process
Ref: V K Jain, et al. (2012)

- *The magnetic iron particles chains structure and force components acting on each NMAP During R-MRAFF process.*
- *The magnitude of magnetic force (Fm) acting on the individual NMAP is given as follows.*

$$F_m = m\mu_o \chi_m H\Delta H$$

Where

m = Mass of a magnetic (Fe) particle
χ_m = mass susceptibility of the magnetic particle
H = magnetic field intensity
ΔH = Gradient of the magnetic field intensity
μ_o = Permeability in free space

- *Axial force (Fa) and radial force (Fr) act on the NMAP due To the reciprocation of the medium by hydraulic unit.*

- *Axial force (Fa) is responsible for shearing.*

- *Radial force (Fr) helps the NMAP in indenting the w/p surface.*

- *Axial force (Fa) and Radial force (Fr) are proportional to the hydraulic extrusion pressure (P) and medium viscosity (Fr=kP) where k is constant.*

- *The total normal indentation force is the sum of these three forces*

$$F_{indentation} = F_m + F_{cen} + F_r$$

Where

F_m = Magnetic force

F_{cen} = Centrifugal force

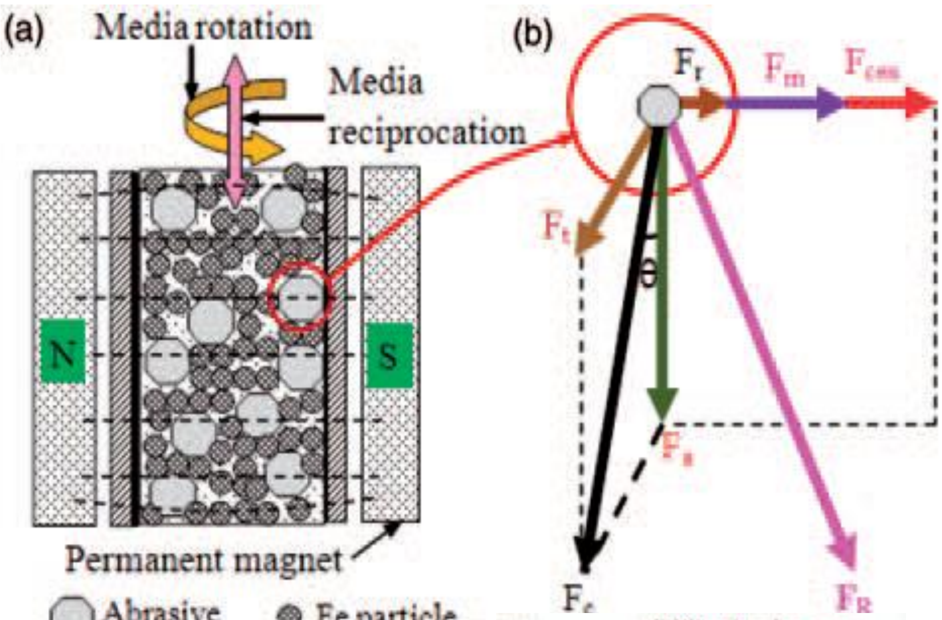
F_r = Radial force

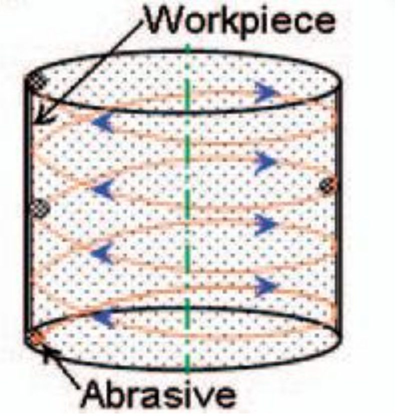
F_t = Tangential cutting force

$$F_{cen} = mr\omega^2$$

$$F_t = 2m(\omega \times v)$$

$$F_c = F_a + F_t$$





- *The resultant force Fc makes the active NMAP to follow a helical path. It produces cross-hatch pattern on the finished Surface*

- *Helix angle and length of the helical path traversed by an active NMAP around the w/p are the function of rotational speed and axial velocity of the medium.*

Higher finishing rate comparison to MRAFF.

Ref: V K Jain et al. (2012)

Thank You

Methods of Micro fabrication

- **Material deposition**
  - *Electro chemical spark deposition*
  - *Electro discharge deposition*
  - *Chemical vapour deposition*
  - *Physical vapour deposition*
  - *Rapid prototyping / rapid tooling*
  - *LIGA*
- **Material removal**
  - *Traditional material removal processes*
  - *Advanced material removal processes*

Micro machining

Traditional

- *μ-turning*
- *μ-milling*
- *μ-drilling*

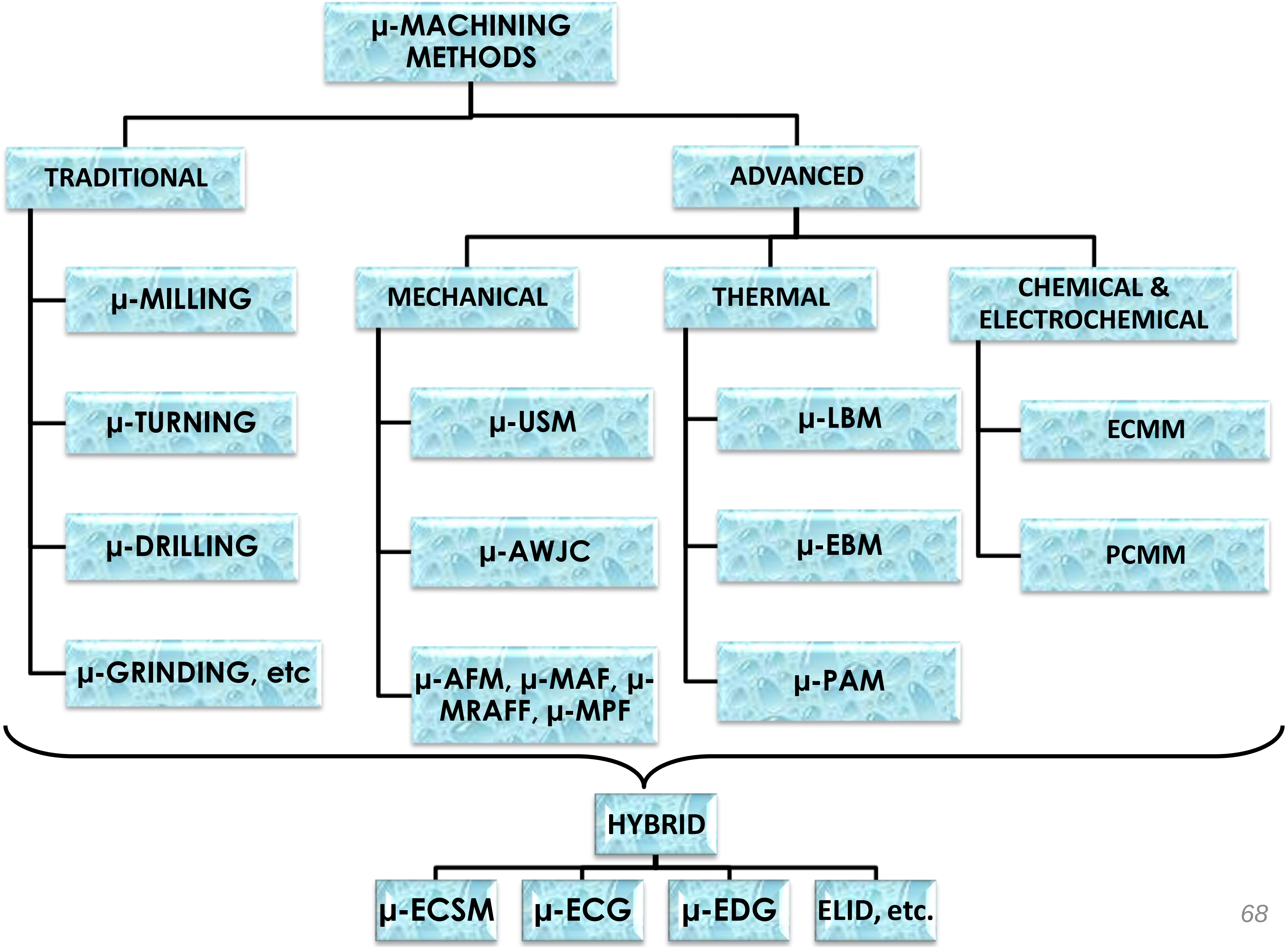
⋮

Advanced

- *μ-EDM*
- *μ-ECM*
- *μ-AJM*
- *LBM*
- *EBM*
- *μ-USM*

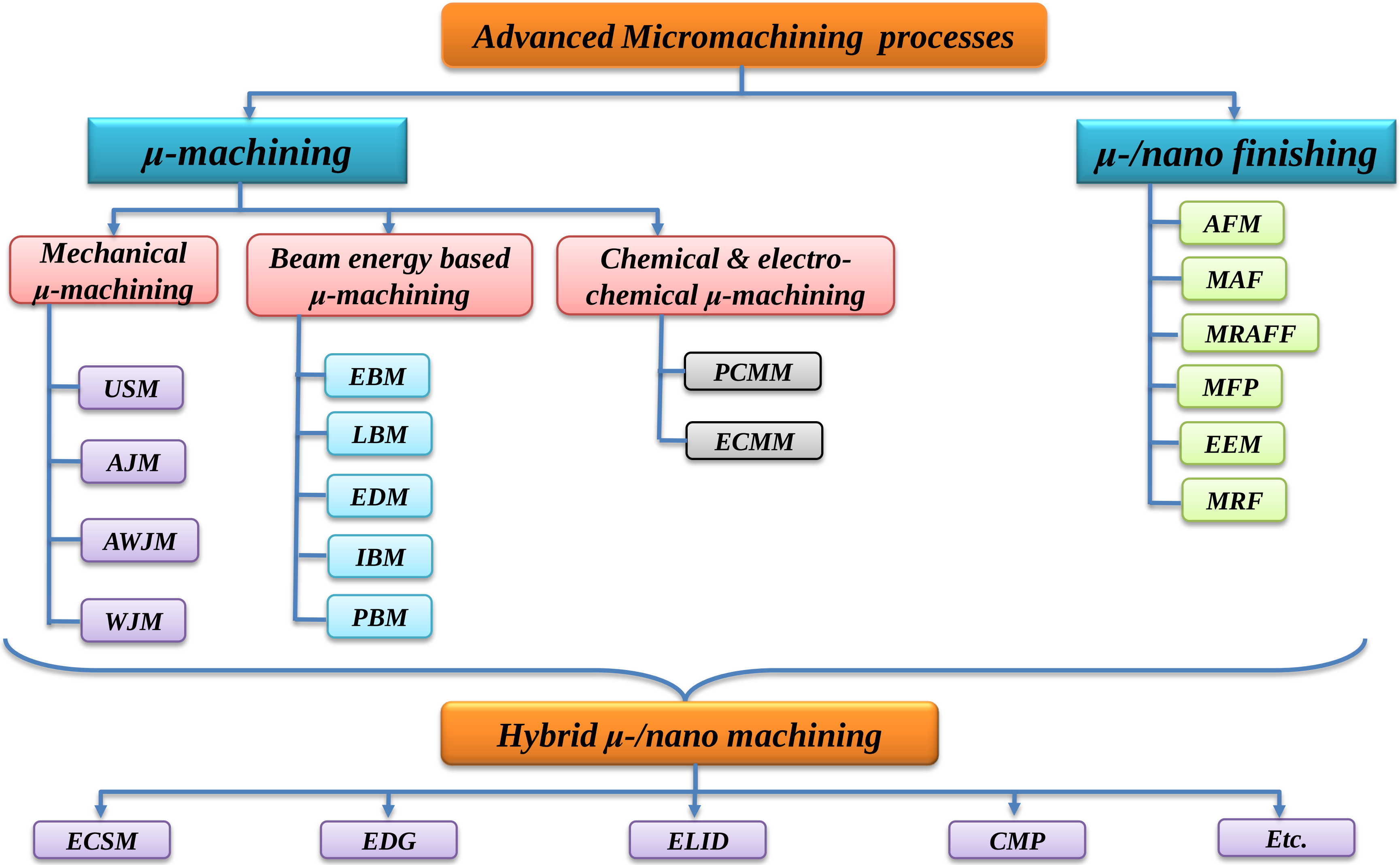
⋮

CLASSIFICATION OF MICROMACHINING



- μ-MACHINING METHODS
  - TRADITIONAL
    - μ-MILLING
    - μ-TURNING
    - μ-DRILLING
    - μ-GRINDING, etc
  - ADVANCED
    - MECHANICAL
      - μ-USM
      - μ-AWJC
      - μ-AFM, μ-MAF, μ-MRAFF, μ-MPF
    - THERMAL
      - μ-LBM
      - μ-EBM
      - μ-PAM
    - CHEMICAL & ELECTROCHEMICAL
      - ECMM
      - PCMM
- HYBRID
  - μ-ECSM
  - μ-ECG
  - μ-EDG
  - ELID, etc.

CLASSIFICATION OF MICROMACHINING AND NANOFINING PROCESSES



Advanced Micromachining processes

- *μ-machining*
  - *Mechanical μ-machining*
    - *USM*
    - *AJM*
    - *AWJM*
    - *WJM*
  - *Beam energy based μ-machining*
    - *EBM*
    - *LBM*
    - *EDM*
    - *IBM*
    - *PBM*
  - *Chemical & electro-chemical μ-machining*
    - *PCMM*
    - *ECMM*
- *μ-/nano finishing*
  - *AFM*
  - *MAF*
  - *MRAFF*
  - *MFP*
  - *EEM*
  - *MRF*

Hybrid μ-/nano machining

- *ECSM*
- *EDG*
- *ELID*
- *CMP*
- *Etc.*

PRINCIPLE OF MECHANICAL ADVANCED MICROMACHINING

Fig: Abrasive water jet micromachining

Fig: Water jet micromachining

Fig: Abrasive jet micromachining

Fig: Ultrasonic micromachining